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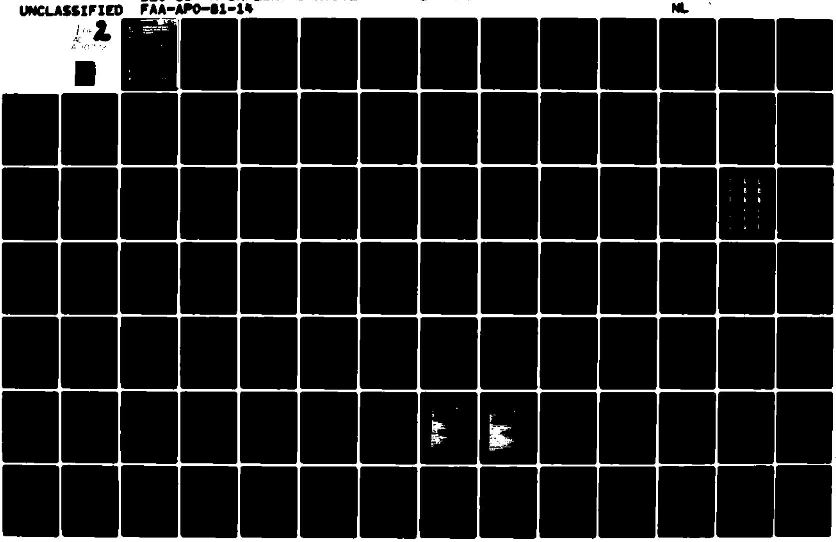

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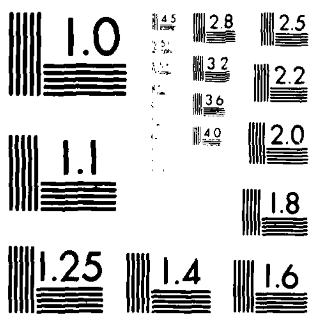

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16. Abstract

A general discussion of the concepts of capacity and delay at airfields and in enroute airspace precedes an estimation of present and future capacity and delay. Options to increase capacity and mitigate delay are then reviewed. The discussion is pointed towards United States air carrier airports and the users of those airports. The most detailed analysis concerns the top 39 air carrier airports and is based on data collection from three major air carriers. Potential congestion problems sufficient to impair the efficiency of national transportation are found to be possible at 19 major airports by 1991. Remedies to such congestion are described for 12 airports, but presently known resources are expected to be insufficient to satisfy the potential demand at 7 airports.

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PREFACE

The research underlying this report was conducted prior to the August 1981 strike by the Professional Air Traffic Controllers Organization. Accordingly, the concepts, assessments of past activity, and estimates of future activity contained in this report are all based on the air transportation system which existed prior to that strike.

Presently, a shortage of air traffic controllers is causing a lack of sufficient capacity to meet the demands of the air transportation system, in both the terminal and the en route airspace. This lack of capacity is reflected in operations limits being enforced at these 22 airports:

Atlanta International
Boston Logan
Chicago O'Hare International
Cleveland Hopkins International
Denver Stapleton
Dallas-Ft. Worth Regional
Detroit Metropolitan Wayne County
Ft. Lauderdale-Hollywood International
Houston Intercontinental
John F. Kennedy International
Kansas City International
Las Vegas McCarran International
Los Angeles International
LaGuardia
Miami International
Minneapolis-St. Paul International
Newark
Philadelphia International
Pittsburgh Greater International
San Francisco
St. Louis International
Washington National

It is expected that pre-strike ATC capacity will be regained during 1983 and that operations limits required by present conditions will be removed. In fact, those limits may be phased out beginning in 1982 as the controller work force grows. The effect of the strike on the capacity and delay topics explored in this analysis is significant at this time, but the subject of this report has a long term nature which will not be substantially altered by the present, temporary situation. The importance and validity of this analysis, therefore, are not affected by the strike.

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EXECUTIVE SUMMARY

Based on directions given in the Federal Aviation Act of 1958 and the Airport and Airway Development Act of 1970, the Federal Aviation Administration has accommodated increased requirements for airport and airway services during the 1970's through expansion of airports and other facilities. In the next decade, economic growth, increases in population, and airline competition are expected to expand air travel. Aviation activity (itinerant and instrument operations at towered airports and IFR aircraft handled en route) are expected to increase by 40 percent.

Prior to the cutbacks in operations necessitated by the 1981 strike by air traffic controllers, significant aircraft delays were encountered at major airports, and federal runway operation quotas existed at Washington National Airport, New York's LaGuardia Airport and Kennedy International Airport, and Chicago's O'Hare International Airport. These conditions of high demand and significant aircraft delays are expected to re-emerge once those cutbacks are eliminated. Expansion of existing airports is frequently difficult, and local communities are likely to impose further environmental restrictions on airport use, thereby reducing capacity. Compounding the threat of potentially inadequate capacity is an increasing unit cost of aircraft delay.

This study assesses the airfield and airspace capacity/delay problem and explores options for mitigating present and future problems.

Two sets of delay information are analyzed--the Standard Air Carrier Delay Reporting System (SDRS) and the National Airspace Command Center (NASCOM) delay reports. These data seem to verify three commonly accepted hypotheses about terminal area aircraft delay:

- o A certain minimum level of delay will probably be encountered at every airport.
- o As traffic density (the number of aircraft seeking runway access during a given period of time relative to runway capacity) increases, the level of delay encountered increases more than proportionately.
- o Disruptive weather conditions, either separately or in combination with high traffic density, cause even higher average levels of delay.

The average, systemwide delay per operation extrapolated from SDRS data was 5.9 minutes in 1980, about an eight percent increase from 1976. This yields an estimated total delay cost to air carriers of about $1.4 billion in 1980. It is believed that a part of this delay is the result of unavoidable arrival and departure queues as well as severe weather, and deducting conservative estimates of these kinds of delay yields a cost of about $0.9 billion in delay which may be subject to some control by the airlines, airports, communities, and the FAA. Airline scheduling practices, especially, appear to be a cause of delays which could be prevented immediately. These delays are apparently tolerable to air carriers and passengers because of the preferable schedules which result from those scheduling practices. Their tolerability casts doubt on the necessity of the FAA to attempt to reduce delays through measures open to it.

Between 1980 and 1991, operations at the 39 largest United States airports are expected to grow by 31 percent. Assuming no change in existing airfield capacity, delay per operation may grow by 47 percent. The combined effect could increase the total cost of systemwide delay to $2.7 billion per year by 1991, about $1.7 billion per year of which may be subject to some control. As at present, a substantial amount of this delay may be unavoidable unless the system users change their current behavior, such as towards peak hour scheduling.

Nineteen of the 39 top airports are expected to experience substantial shortages of capacity to accommodate projected traffic levels. These 19 airports accounted for 51.4 percent of air carrier enplanements in 1979. For seven of the 19 airports, capacity shortfalls might be alleviated largely by diversion of general aviation traffic and some redistribution of traffic into off peak hours. At four airports, diversion of air carrier traffic to other nearby airports can provide substantial congestion relief. There remain, however, eight airports where diversion of general aviation traffic will not provide adequate congestion relief and alternate facilities for air carrier traffic are not readily identifiable at this time. Many of these eight airports serve as key connecting points in the national air transportation system or links to the international air transportation system.

Except for the temporary shortage of controllers caused by the 1981 strike, en route air traffic control capacity is considered adequate for current traffic levels. A substantial amount of en route airspace is underutilized at this time, and, ignoring the problems caused solely by the controller shortage, delays caused en route are believed insignificant.

Projected levels of future en route traffic can probably be accommodated using current control technology, provided that adequate levels of FAA staff and facilities are available. Computer capacity may constitute a significant constraint to enroute traffic before 1990. Also, entry to and exit from the en route system--the hub-en route boundaries--may constitute potential capacity problems for several en route centers.

Several options are identified to reduce airfield and airspace congestion. Airfield actions considered in the report include airport development, air traffic procedures, nontechnical actions (administrative and economic measures) and other actions including the use of larger aircraft and organizational devices. Airspace capacity measures evaluated include air traffic procedures and nontechnical actions. Tables E-1, E-2, and E-3 summarize key characteristics and the applicability of various potential airfield and airspace initiatives. Many of the characteristics of these initiatives, especially the acceptance by communities and operators, are based on the experience and judgment of FAA analysts.

TABLE E-1

CHARACTERISTICS OF OPTIONS TO INCREASE AIRFIELD CAPACITY/REDUCE DELAY

	Physical/ Technical Possibility	Type of Impact	Cost		Operator Acceptance	Community Acceptance
			FAA	User		
Short Runways	Moderate to High	Increase Capacity	$10 Million each	Unknown	High	Moderate
Satellites/Relievers (Divert GA Traffic)	High	Increase Capacity	$93 Million	Low	AC - High GA - Moderate	Moderate
Reduce Runway Occupancy Time	Low	Increase Capacity	Unknown	Unknown	Low	Moderate
Wake Vortex Alleviation and Detection	Low	Increase Capacity	Unknown	Unknown	Moderate	Moderate
Dual Glide Slopes	Low	Increase Capacity	Low	Moderate	Low	Low
Traffic Segregation	Moderate	Increase Capacity	Low	Low	Moderate	Moderate
Traffic Sequencing	Low to Moderate	Increase Capacity	Unknown	Low	Low to Moderate	Moderate
Parallel/Converging Approaches	Moderate	Increase Capacity	Low to Moderate	Moderate	Moderate	Moderate
Flow Control	Moderate	Mitigate Delay	Low	Low	Moderate	Moderate
Divert AC Traffic - Agreements	Moderate	Reduce Delay	None	Unknown	Low to Moderate	Moderate

TABLE E-2

POTENTIAL AIRFIELD APPLICABILITY OF OPTIONS TO INCREASE CAPACITY/REDUCE DELAY

	High GA							Alternate Airports				Extra Capacity							
	OAK	IAH	SNA	LAS	MEM	PHX	SAN	SFO	DFW	ORD	DCA	ATL	BOS	DEN	LAX	PHL	STL	LGA	JFK
Short Runways									1/	1/		X		X		X	X		X
Satellites/Relievers (Divert GA Traffic)	X	X	X	X	X	X	X	1/	1/	1/	1/	X	X	X	X	X	X	X	X
Reduce Runway Occupancy Time	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wake Vortex Alleviation and Detection	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Traffic Sequencing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Parallel/Converging Approaches		X		X	X	X		X		X		X	X	X	X	X	X		
Flow Control									X	X		X	X	X					
Divert AC Traffic - Agreements								X	X	X	X	X	X	X	X	X	X	X	X

1/ Physically possible but not considered a good alternative.

TABLE E-3

CHARACTERISTICS OF OPTIONS TO INCREASE AIRSPACE CAPACITY/REDUCE DELAY

	Physycal/ Technical Possibility	Type of Impact	Cost		Operator Acceptance
			FAA	User	
Alternate Altitude Assignment	Moderate to High	Increase Capacity	Low 1/	Low to Moderate	Moderate
1,000 Foot Vertical Separation Above 29,000 Feet	Moderate	Increase Capacity	Low 1/	Low	High
En Route Flow Control	Moderate	Mitigate Impact of Delay	Low to Moderate	Low	Moderate
Pilot Based Control	Unknown	Increase Capacity	Low?	Low to Moderate	Moderate to High
Electronic Flight Rule Concept	Unknown	Increase Capacity	Low?	Low to Moderate	Moderate to High

1/ Must consider additional cost of increased scale of en route facilities and equipment.

I. INTRODUCTION

The Federal Aviation Act of 1958 directs the Secretary of Transportation to consider (among other things) the following items as being in the public interest:

- Promotion, encouragement, and development of civil aeronautics;
- Control of the use of the navigable airspace of the United States and the regulation of both civil and military operations in such airspace in the interest of the safety and efficiency of both; and
- The development and operation of a common system of air traffic control and navigation for both military and civil aircraft. 1/

The act also recognizes a citizen's public right of transit through the navigable airspace of the United States. 2/

Given these directions, the Federal Aviation Administration (FAA) has expanded the airport and airway system. Table 1 contains statistics on airport and airway activity which reflect the rapid growth of aviation between 1960 and 1980. Over those twenty years, itinerant operations at towered airports increased 150 percent, instrument operations at these airports rose 500 percent, and aircraft flying the Federal airway system under instrument flight rules (IFR) increased 200 percent.

1/ 72 Stat. 740, 49 U.S.C. 1303.
2/ 72 Stat. 740, 49 U.S.C. 1304.

TABLE 1

AIRPORT AND AIRWAY ACTIVITY
1960-1990
(Millions of Operations)

	1960	1970	1980	1990 1/
Itinerant Operations at Towered Airports				
Air Carrier	7.3	10.8	10.1	12.3
Air Taxi	N/A	N/A	4.6	8.8
General Aviation	8.7	22.6	28.3	42.5
Military	2.1	1.5	1.2	1.2
	18.1	34.9	44.3	64.8
Instrument Operations at Towered Airports				
Air Carrier	N/A	10.2	10.6	12.6
Air Taxi	N/A	N/A	4.1	8.2
General Aviation	N/A	4.1	19.3	29.1
Military	N/A	3.2	4.1	4.3
	6.4	17.5	38.2	54.2
IFR Aircraft Handled at En Route Centers				
Air Carrier	5.5	13.5	13.9	16.5
Air Taxi	N/A	N/A	2.6	5.2
General Aviation	.6	3.6	8.9	15.8
Military	3.7	4.5	4.7	4.7
	9.8	21.6	30.1	42.2

1/ Forecast
N/A = Not separately available

By the late 1960's, Congress found the airport and airway system inadequate to meet the growth in aviation. It therefore enacted the Airport and Airway Development Act of 1970 and Airway Revenue Act of 1970. This law, and subsequent amendments, established a new program of Federal aid to airports, increased funding authorizations for airport and airway facilities and equipment, and also increased funding for FAA research and development activity. Between 1971 and 1980, Federal airport grants, facility and equipment expenditures, and research and development expenditures were $3.3, $2.2, and $0.7 billion, respectively.

During the 1970's, these resources provided additional capacity to accommodate air traffic. The number of Federal facilities increased substantially—towers up 43 percent, instrument landing systems up 117 percent, airport surveillance radar up 38 percent, and air route surveillance radar up 23 percent. The mileage of Federal airways rose 19 percent at high altitudes and 8 percent at low altitudes for the 48 coterminous states.

It was not possible, however, to provide adequate capacity to meet all demands for service. For example, as a result of extreme congestion problems experienced in 1969, the FAA imposed limits on the number of hourly operations at five major airports. Those quotas still exist at Washington National (DCA), LaGuardia (LGA), John F. Kennedy International (JFK), and O'Hare International (ORD) Airports. At the same time, community concern about increased levels of noise and air pollution produced by commercial and private aircraft manifested itself in numerous Federal and local environmental laws. In the last several years, local restrictions—quotas and/or curfews—have been imposed or proposed at individual airports to reduce adverse environmental impacts. These limits often reduce airport capacity in situations of increased demand for service.

A. The Problem

Growth of the national economy, increases in population, and airline industry deregulation are expected to expand air travel in the long term. Airline deregulation may also alter the pattern of airline activity by increasing the concentration of air carrier service at large hubs and further expanding the commuter airline industry (see The Changing Airline Industry: A Status Report Through 1979 and its 1980 update [16,45]).

According to official FAA forecasts (see Table 1), aviation activity (itinerant and instrument operations at towered airports and IFR aircraft handled en route) is expected to increase by 40 percent over the next decade. Substantial increases are projected for both commuter and certificated, scheduled air carriers, but most of the growth is attributed to general aviation.

Prior to the cutbacks in operations necessitated by the 1981 strike by air traffic controllers, significant aircraft delays were encountered at major airports. Expansion of existing airports is frequently difficult, and local communities are likely to impose further environmental restrictions on airport use, thereby reducing existing capacity.

Given all of the above, it may be argued that the future efficiency of U.S. air transportation is threatened by inadequate capacity. Compounding the threat of potentially inadequate airport and airspace capacity is an increasing unit cost of aircraft delay. The hourly operating cost (including maintenance and depreciation) of a B-727-200 aircraft grew from $1048 in 1976 to $1,989 in 1980—a 90 percent increase. By comparison, the Gross National Product Price Index increased 36 percent between 1976 and 1980.

B. Legal Authority of the FAA

The navigable airspace of the United States is a limited resource which may be unable to accommodate all those who wish to use it. This fact was recognized during the development of legislation which ultimately became the Federal Aviation Act of 1958. Senate Report No. 1811, 85th Congress, 2nd Session, July 1958, specifically discusses the navigable airspace of the United States as a "diminishing resource".

The authority of the FAA to control the use of the navigable airspace is total and is contained in Section 307 of the Federal Aviation Act [49 U.S.C. 1348]. Subsection (a) authorizes and directs the Administrator of

FAA to control the use of the navigable airspace, and Subsection (c) authorizes and directs him to prescribe air traffic rules and regulations governing the flight of aircraft through the navigable airspace. It should be noted that the statutory language does not merely authorize the Administrator to act with respect to control of the navigable airspace, it directs him to act. This language creates an affirmative duty on the part of the Administrator to promulgate rules and regulations concerning use of the navigable airspace and to control such use.

Every court which has considered the question has upheld and reaffirmed the totality of Federal control of the navigable airspace and air traffic. See Air Transport Association v. Crotti, 389 F. Supp. 58 (three judge court, N.D. Cal. 1975); American Airlines v. City of Audubon Park, 407 F.2d 1306 (6th cir. 1969); Allegheny Airlines v. Village of Cedarhurst, 238 F.2d 812 (2d Cir. 1956). The recently enacted Aviation Safety and Noise Abatement Act of 1979 (P.L. 96-193, Section 104(b)) authorizes airport operators to propose flight operation/air traffic control procedures, but the approval or disapproval of such procedures is reserved to the Administrator of FAA. In short, the totality of Federal control, more specifically control by the Administrator of FAA, of the navigable airspace has not been diminished in the 22 years since establishment of that control in the 1958 Act.

Section 307(b) authorizes the Administrator to establish and improve air navigation facilities "within the limits of available appropriations made by the Congress." All of the technological progress by the FAA concerning air navigation facilities and airspace control is related to the two standards established by Subsections (a) and (c) of Section 307. Those standards are (i) the safety of aircraft operating in the navigable airspace and (ii) the efficient use of navigable airspace. Based on those standards, this analysis has been undertaken in order to promote the efficient use of navigable airspace.

C. Study Objectives

The objectives of this study are as follows:

- Assess the airfield and airspace capacity/delay problem; and

- Describe the options for mitigating present and future problems.

While capacity and delay problems are also associated with the airport terminal building and/or ground access to the terminal, these problems are outside the scope of the present study. Also, the extraordinary situation created by the 1981 strike by air traffic controllers is assumed to be temporary and is not considered as a factor in this analysis.

D. Approach

This analysis has been an eclectic enterprise. Estimates of capacity and delay were obtained from existing FAA information systems and prior studies. The estimates were combined with FAA aviation activity forecasts to estimate future congestion. Options for accommodating future demand were described by combining program assessments provided by FAA Associate Administrators with staff research undertaken by the Office of Aviation Policy and Plans (APO).

E. Organization of the Report

Chapter 2 contains background information on capacity and delay, and Chapter 3 contains estimates of present and future airfield and airspace capacity/delay. Options to accommodate future demand are described in Chapter 4. Conclusions comprise the last chapter. Several appendices provide more detailed information.

II. BACKGROUND ON AIRFIELD AND AIRPSPACE CAPACITY AND DELAY

Capacity and delay are illusive concepts, surrounded by confusion and misunderstanding. A substantial part of this problem is that multiple definitions are interchangeably used and that incomplete data are collected by multiple sources for varying purposes. The problem is further compounded by the difficulty in determining cause and effect relationships from the data which are available. The following discussion is intended to set a framework of discussion for the dual issues of capacity and delay.

A. Capacity Concepts

Two principle definitions of capacity have been advanced in discussions of terminal area capacity: (1) a so-called "practical" measure, and (2) a "throughput" measure. The "practical" measure provides a measure of capacity which is defined with respect to a maximum acceptable average delay. (Practical annual capacity, PANCAP, is one well-known measure of this type.) The "throughput" measure is a measure of capacity independent of delay; it assumes that an aircraft will always be present waiting to use the terminal. A clear distinction between the two requires a brief description of the delay process.

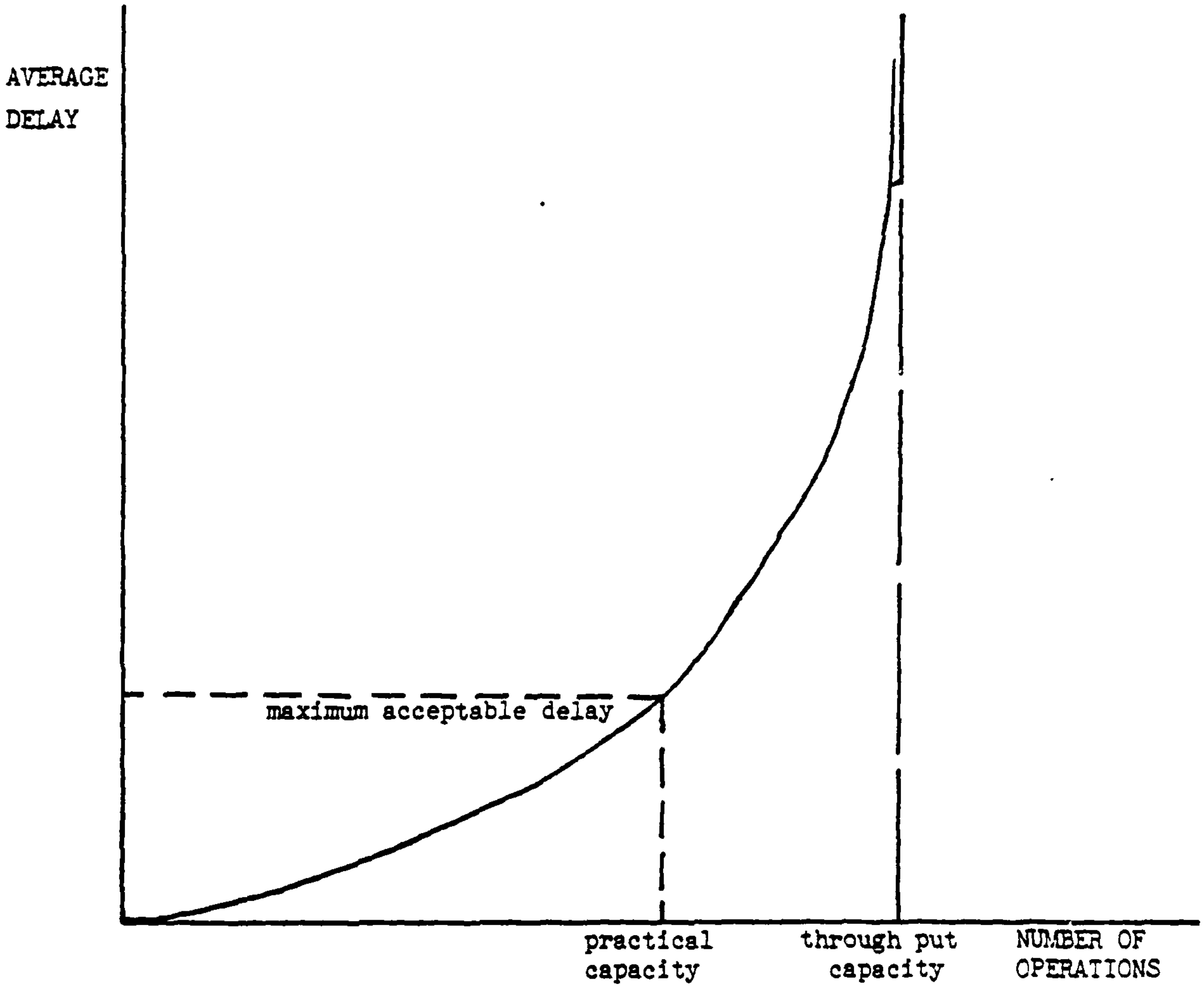
If all users of a system consistently arrived at evenly spaced intervals, the system could provide service hourly to a number of users equal to the service time in minutes divided into 60. This is the maximum possible service rate and is the "throughput" measure of capacity. Unfortunately, system users do not arrive consistently at evenly spaced intervals. Sometimes several users arrive at one time and sometimes no one arrives. As a consequence, some of those who arrive at the same time as do others must be delayed. Also, runway occupancy times vary from operation to operation, and runway occupancy time is a major constraint on the service rate. The "practical" capacity measure is the number of users that can be served hourly with the average user incurring delay of a certain level, after taking into account these factors.

The two measures are illustrated by Figure 1 which indicates the theoretical relationship between capacity and delay. As can be seen, the "throughput" measure is the maximum capacity attainable. It results in very high average delay levels—infinite at the limit—as a consequence of the unevenness of arrivals. The "practical" measure is less than the "throughput" measure. It is that level of capacity utilization which corresponds to a given acceptable level of delay.

Although both measures have been used in studies of terminal delay, the "throughput" measure seems to have received more attention in later work. This is because it is relatively simple to calculate and independent of delay. In addition, being independent of delay, it is not

FIGURE 1

RELATIONSHIP BETWEEN CAPACITY
AND AVERAGE DELAY



affected by and will not vary with different delay calculation schemes. The "throughput" measure is thus comparable from situation to situation, regardless of the delay estimation techniques employed in each situation.

It should be pointed out that the relationship depicted in Figure 1 may not always be observed in the real world, because Figure 1 is drawn on the presumption of a single processing rate for all levels of operations. In reality, the processing rate may vary directly with the number of operations for a number of reasons. For example, staffing levels are almost always positively correlated with expected traffic, and controller productivity may increase as demand increases. Also, some systems (such as the en route airway system) may have more than one processing system (route between two terminals), each with a different processing time. As a waiting line develops behind the most efficient system, some of those waiting may turn to the second, third, and so on, most efficient system. Users served by these less efficient systems, while actually spending more time being served, will save enough waiting time to reduce overall time.

The impact of the processing rate increasing as the level of operations increases will be to shift the delay-capacity relationships downward. The observed relationship will be below the curve as drawn in Figure 1, and, if the processing rate should increase fast enough over a particular range of operations, the observed level of delay might actually decline over a particular range of operations.

B. Delay Concepts

Delay may be defined as the difference between actual trip (segment) time and a standard trip (segment) time. Several alternatives exist for the standard time—average actual time, shortest actual time, or a theoretical trip time derived from aircraft and airport/airway system performance specifications.

1. Acceptable Delay

Strictly speaking, some delay may be associated with most trips. Whether this delay is significant, however, depends on what level of delay is judged to be "acceptable."

Adoption of "acceptable" delay standards is an exercise in public policy, and there are several criteria which the policymaker should consider in the establishment of these standards. First, part of all delay occurs because of conditions beyond anyone's control. Such conditions include variations in wind, precipitation, pilot proficiency and aircraft performance. Because there is little that can be done about such factors, there is little choice but to treat the delay they cause as "acceptable." Second, the economics of delay reduction investments should be considered. Under a strict economic criterion, investments in delay reduction should continue to be made until the benefits associated with such investments just equal the cost of undertaking them. The level of "acceptable" delay is that level which prevails when this economic condition obtains.

"Acceptable" delay is, thus, that level of delay which it does not pay to eliminate. Third, it must be recognized that delay is a random phenomenon. Sometimes a flight will experience small or no delays, while at other times delays will be large. Large delays generate problems in terms of scheduling, passenger connections, and maximum aircraft flying times. Accordingly, the policymaker must consider the maximum acceptable level of delay, above which an unacceptable disruption to the air transportation system would be experienced.

2. Delay Classifications

Delay is commonly classified by the segment of airspace where it is experienced. The point at which delay is experienced, however, may or may not coincide with the location of the cause of the delay. Information concerning the airspace segment where delay is caused is important in that it focuses attention on segments of airspace with insufficient capacity. Knowledge of where the delays actually are experienced is important in that it identifies where the delayed aircraft must actually be accommodated. Moreover, since some agency delay programs such as "flow control" seek to move delays from one airspace segment to another, such information is essential if these programs are to be evaluated.

Figure 2 relates the potential sites of aircraft delay cause with sites of aircraft delay experience.

FIGURE 2

POTENTIAL RELATIONSHIPS BETWEEN

AIRCRAFT DELAY CAUSE AND EXPERIENCE SITES

Cause Location: / Experience Location:	Departure Terminal	En Route	Arrival Terminal
Departure Terminal	Yes	Yes	Yes
En Route	No	Yes	Yes
Arrival Terminal	No	No	Yes

Delay caused in a particular airspace segment cannot actually take place in airspace segments which the aircraft encounters after the segment of delay origin. As an analogy, water backs up behind a dam, not in front of it. An exception might be when departure delays cause arrival delays because there are too many aircraft on the airport surface to permit additional aircraft to be landed. Although these types of exception do occur, they are for the most part atypical. The following paragraphs describe each type of delay and where it occurs.

a. Departure-Terminal: This delay is caused by events at the departure terminal and occurs exclusively at this terminal. The most frequent cause is weather. Because the situation is known to all potential departures, this type of delay is taken almost exclusively on the ground—where it is least costly.

b. <u>En Route</u>: En route delay occurs whenever an aircraft must take longer to complete a trip than the minimum achievable time. Such delay occurs because the optimum route is not available for the aircraft for one of a number of reasons: (1) traffic volume between the two terminal areas may exceed that which may be accommodated by the optimum route, (2) severe weather may result in the optimum route being closed, (3) heavy traffic volume across the optimum route may require that an alternate route be flown. Delays generated by en route events most likely will occur in the en route airspace. It is possible under extreme conditions that such delays may back up into the terminal area. If they do back up into the departure terminal, they will most likely be taken on the ground.

c. <u>Arrival Terminal</u>: Delays generated in the arrival terminal airspace occur because the terminal cannot land aircraft at the rate they are arriving. This delay may actually occur in the terminal area but most often backs up into en route airspace. This avoids congestion in the terminal area and permits aircraft to hold at higher altitudes where they are more fuel efficient. (Note that most holding stacks are in en route airspace.) At times, these delays may back up all the way to the departure terminal where aircraft bound for congested terminals will be held on the ground.

C. Factors Affecting Airfield Capacity and Delay

Airfield capacity and delay is a complex topic involving the interaction of many factors. It has been the subject of much study, and a large body of knowledge has been developed on the subject. The same is not true for en route capacity and delay, simply because it has been considered to be of relatively little significance compared to the airfield problem. Information on the factors affecting airspace capacity and delay is incorporated in Chapter III.B. The following section concentrates on the airfield area.

Delay is essentially determined by an airfield's traffic density, which reflects the continuously changing relationship between that airfield's capacity and aircraft demand for use of that airfield. Airfield capacity is determined by many factors, which may be grouped into six categories:

- ATC rules, regulations, and procedures;
- Physical properties of the airfield/airspace;
- Meteorological conditions;
- External constraints;
- Operational factors; and
- Aircraft demand.

Note that aircraft demand, which acts in conjunction with capacity to determine traffic density, is also a factor in determining capacity. Further complicating the issue is the fact that delay, which results from too high a traffic density, can affect aircraft demand. For example, general aviation pilots have been found to be keenly aware of delay levels and often are willing to change their flight plans accordingly.

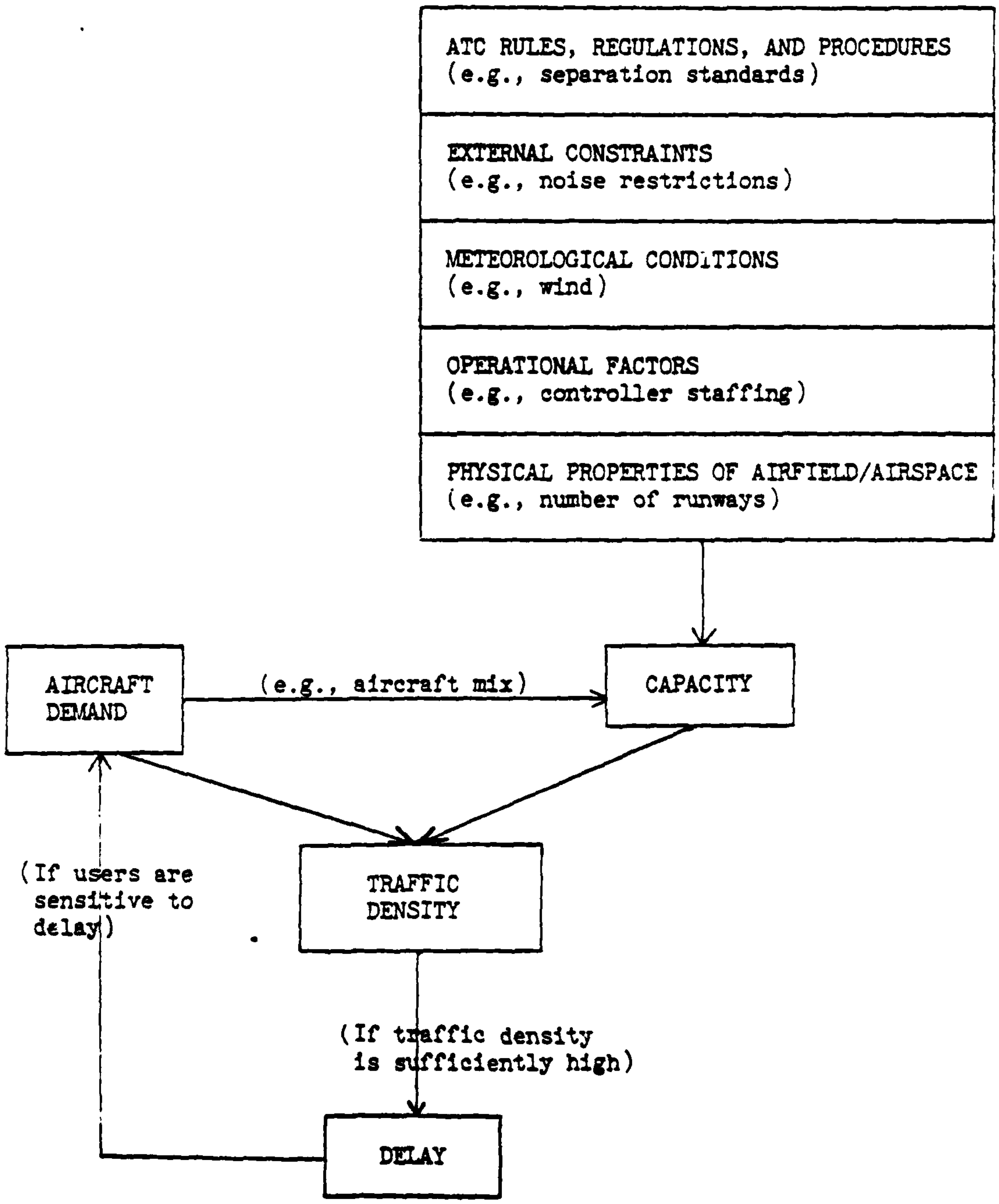
Figure 3 is a summary of the interaction of the variables mentioned above. Each category of factors affecting capacity and delay is described below.

1. Air Traffic Control (ATC) Rules, Regulations, and Procedures

Although designed to ensure operational safety in the airport environment, certain ATC rules, regulations, and procedures limit airfield capacity and affect delays. While ATC rules and regulations are absolutely necessary for safety of operation, their relationship to capacity and delay should be understood. The rules and regulations most affecting capacity and delay are those regarding separation requirements between arriving and departing aircraft. While it is not suggested that delay reduction be achieved through modifying the rules or procedures, one should understand why a certain level of delay is inherent any time there is a heterogeneous mix of aircraft operating at an airport.

FIGURE 3

FACTORS AFFECTING CAPACITY/DELAY



a. Arrival Separations

Current ATC rules under IFR conditions stipulate that certain distances must be maintained between arriving aircraft of different weight classes. The current IFR separation standards are 3, 4, 5, 4, and 6 nautical miles (LL, HH, HL, LS, HS).1/ In comparison, the observed separation under VFR is significantly less under saturated traffic conditions. Table 2 summarizes these IFR separation standards and observed VFR separations.

b. Runway Occupancy

The second basic ATC rule is that two aircraft may not both occupy the same runway. Once the first aircraft crosses the threshold, it has sole possession of the runway until it exits. The second aircraft must be spaced such that it does not cross the runway threshold until the first has cleared the runway.

c. Departure/Arrival Spacing

Current operating rules prohibit the initiation of a departure unless the following arrival is more than two miles out from the threshold.

1/ S, L, H refer to ATC weight classes:

Small (S): Less than 12,500#
Large (L): Between 12,500# and 300,000#
Heavy (H): Greater than 300,000#

Notation "HL", for example, denotes heavy followed by a large aircraft. The notation "LL" includes all pairings not otherwise specified (i.e., SS, SL, SH, LL, LH).

TABLE 2

MINIMUM AIRCRAFT SEPARATIONS

A) Departure Separations (Seconds)

IFR

Lead \ Trail	S	L	H
S	60	60	60
L	60	60	60
H	120	120	90

VFR

Lead \ Trail	S	L	H
S	35	45	50
L	50	60	60
H	120	120	90

B) Arrival Separations (Miles)

IFR

Lead \ Trail	S	L	H
S	3	3	3
L	4	3	3
H	6	5	4

VFR

Lead \ Trail	S	L	H
S	1.9	1.9	1.9
L	2.7	1.9	1.9
H	4.5	3.6	2.7

S = Small
L = Large
H = Heavy

d. <u>Departure Separation</u>

Current IFR operating rules define the minimum departing separation. Further, due to the wake vortex problem, VFR standards for aircraft following a heavy are the same as IFR standards to ensure the safety of aircraft which takeoff after a heavy aircraft.[1/] The current IFR standards are HH: 90 seconds; HL, HS: 120 seconds; all others: 60 seconds. Table 2 summarizes these standards.

e. <u>Parallel and Crossing Runways</u>

Current rules stipulate arrival and departure separation standards for aircraft using certain closely spaced parallel and triple parallel runways, and for aircraft using crossing runways which require projected flight paths to cross.

2. <u>Physical Properties of the Airspace/Airfield</u>

The physical properties of an airport's airspace/airfield determine not only the ability of the entire system to accommodate various aircraft types, but also the operating efficiency of the configurations in which the airfield functions. The following are examples of physical properties which affect capacity and delay:

1/ Every airplane in flight generates a pair of counter rotating vortices trailing from the wing tips. The vortices from large aircraft pose problems to encountering aircraft.

- Lighting, radar, and other equipment;
- Number and lengths of runways;
- Obstructions and equipment outages;
- Displaced thresholds reducing usable runway length;
- Shoulders on runways;
- Intersection and exit locations and number;
- Location of airline gates vis-a-vis runway exits;
- Weight limitations on runway segments; and
- Proximity of other airports.

The proximity of other airports to the specific airport being analyzed affects delays to the extent that their operations limit the paths over which aircraft may be vectored to or from the subject airport, and to the extent that their operations must be coordinated through approach control or the tower. Delays can be the result of a requirement to hold departures at one airport until arrivals have cleared at the other one, or a gap may be required in the arrival stream for one airport to accommodate arrivals or departures from the other airport.

Delays may also be incurred when less than optimal routing is required in order to preclude incursion into the airspace of an adjacent airport. These routings can take the form of longer distances before turns are initiated in order to attain sufficient altitude to climb over conflicting approach paths or long approach legs at low altitudes to pass under conflicting flight tracks.

3. Meteorological Conditions

The operational strategy of an airfield is governed to a large extent by considerations of ceiling, visibility, precipitation, and prevailing wind directions. These conditions determine not only what runway configuration will be in operation, but the control procedures to be used in processing aircraft to and from the field. Figure 4 shows 18 possible runway use combinations at O'Hare International Airport. An arrowhead pointing to a runway end indicates landing directions, an arrowhead emanating from the runway end indicates takeoff direction. Figure 5 shows the combined effects of weather (IFR versus VFR) and runway configuration specific capacity on average delay per operation. With a constant demand, average delay can range between 3 minutes per operation and 37 minutes per operation. Therefore, when the winds dictate the use of a high delay configuration, a premium in terms of increased delay is paid for its use.

Ceiling and visibility also affect the selection of operating configurations. Depending upon instrumentation and conditions affecting their use, landing minimums can vary from runway to runway, necessitating adjusting the operating configuration to the prevailing ceiling and visibility conditions irrespective of the capacity of the runway combination. As an example, meteorology can affect delays in even the most efficient configuration at O'Hare. Visual approaches (in which the pilot visually determines his own separation from the preceding aircraft) may not be conducted when the ceiling and visibility limits fall below

FIGURE 4

RUNWAY CONFIGURATION - O'HARE INTERNATIONAL AIRPORT

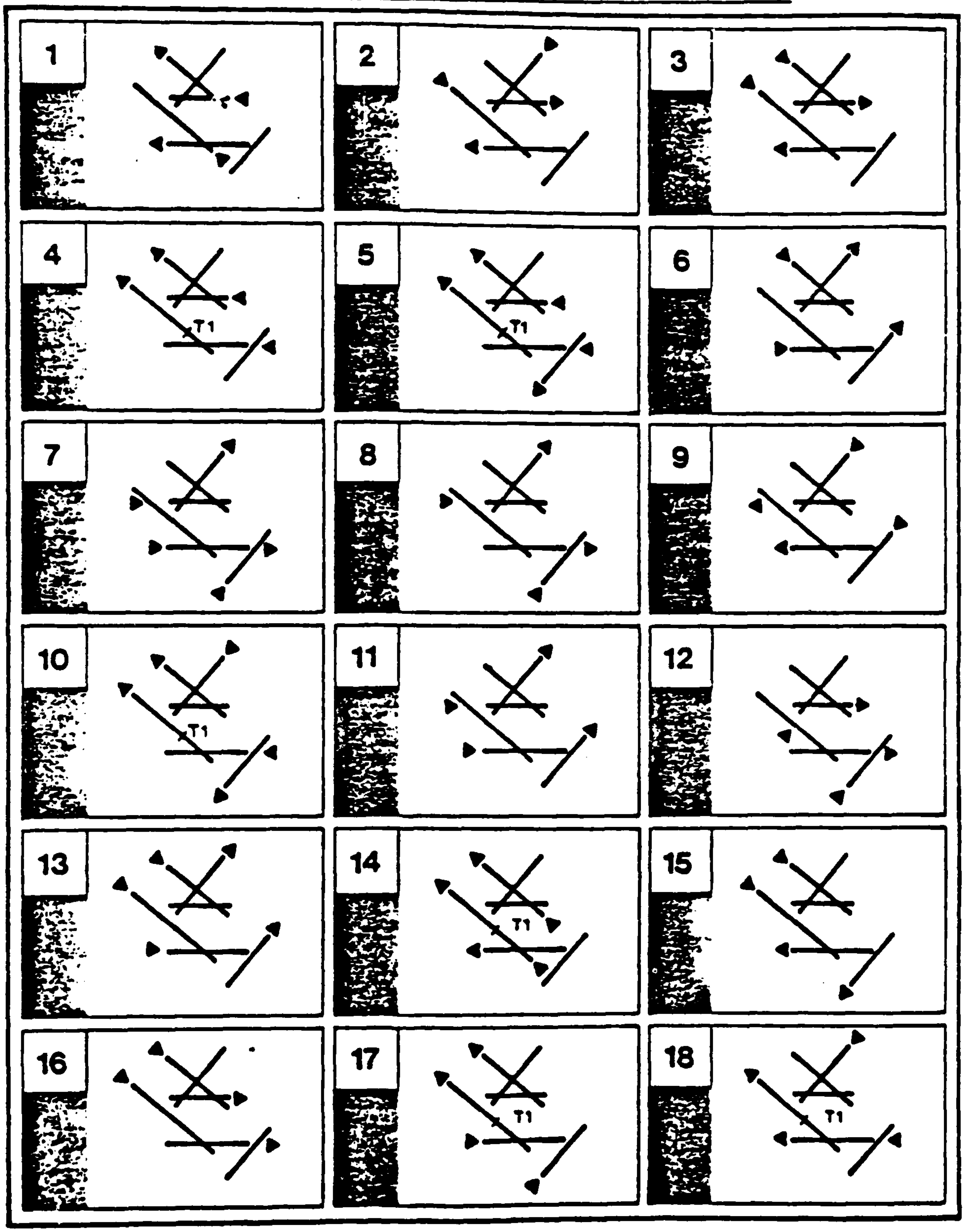
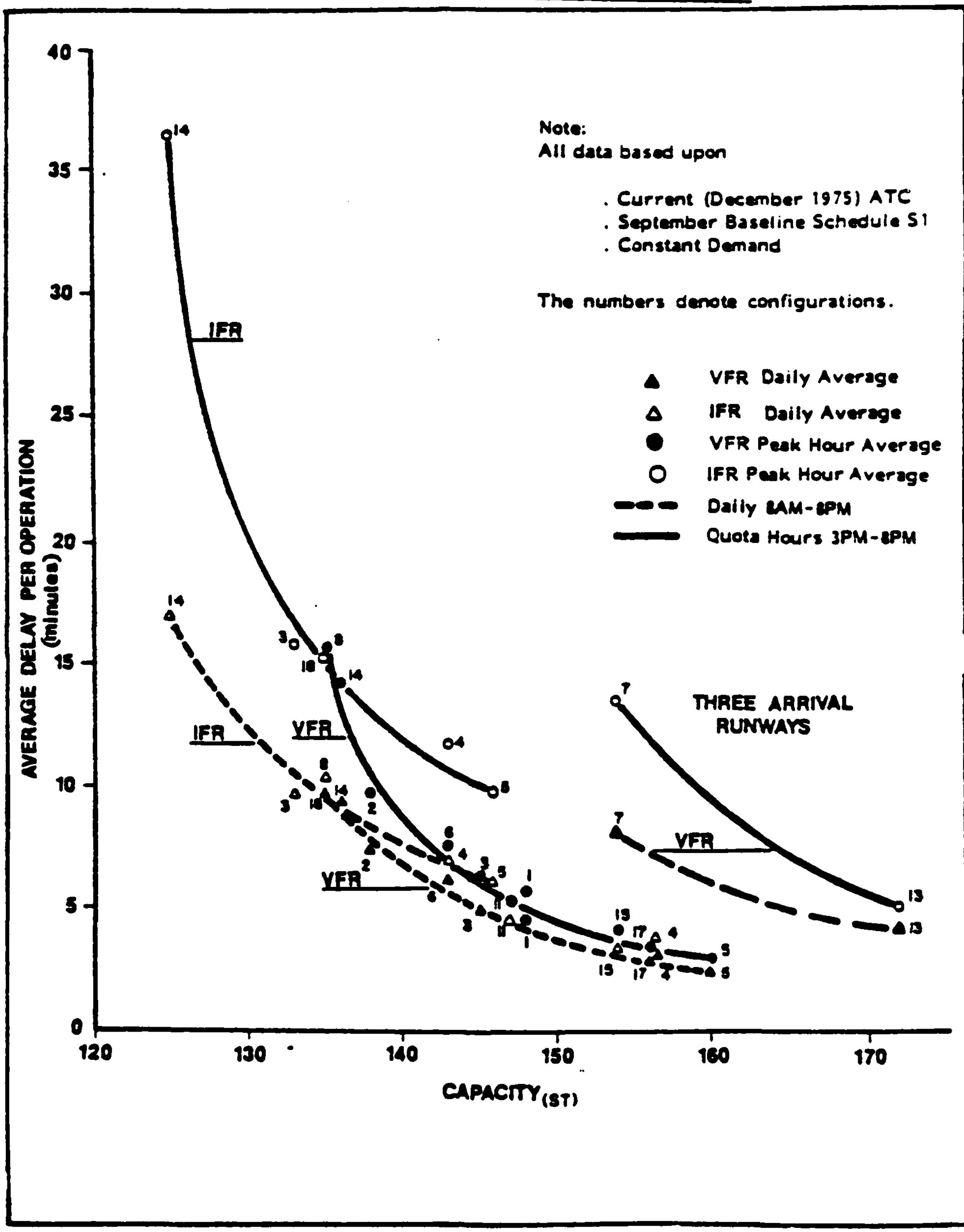


FIGURE 5

DELAY VERSUS CAPACITY - O'HARE TASK FORCE STUDY



3,500 feet and 5 miles, respectively. This causes an increased spacing between arrivals, thereby decreasing capacity and increasing delay. As the ceiling and visibility approach IFR limits (1000/3), the spacing between arrivals again increases to allow a greater safety buffer between operations. In conditions of very low visibility, i.e., less than 500/1, visual observation of the runway system is not possible, requiring additional controller caution and increased dependence on pilot/controller communication, all of which further reduce the efficiency of the airfield system.

The condition of the runways themselves can increase spacing and therefore increase delays, by reducing aircraft braking performance and increasing runway occupancy time. In addition, snow or ice on the runways will require periodic runway closures for maintenance to ensure safe operating conditions.

Short term phenomena such as ground fog or the passage of a frontal system accompanied by severe turbulence can result in the holding of departures on the ground and inbound aircraft in holding stacks. These conditions, although generally of short duration, often cause delays of major proportions due to the backlog of demand created.

4. External Constraints

The major external contraint affecting the operational configuration of an airfield is a locally imposed restriction on runway configurations for purposes of noise abatement. Curfews affecting hours of operation and quotas affecting operations per hour are imposed at several airports, as well.

5. Operational Procedures

Operational factors are those elements of the airfield environment which reflect human and organizational control. These factors include the number and competence of controllers relative to the workload, the competence of pilots, the communications between controllers and pilots, the efficiency in bringing aircraft into and out of the airfield, and the choice of runway configuration.

Several considerations enter into the selection of runway configurations, most notably meteorology and, at some airports, noise abatement. While wind direction and velocity are key determinants in the selection and changing of runway configurations, selection decisions remain the responsibility of FAA air traffic control management (multiple configurations can be used for given wind conditions).

The unavailability of runways for use due to scheduled maintenance, construction, and weather related problems, such as snow removal, also contributes to delay. Unavoidable weather related problems are the primary reason for unscheduled "down" runways. However, scheduled maintenance and construction are a necessary and on-going function of any airport's operation, which can contribute to delays. Airport management procedures have not always provided for detailed operational analyses prior to maintenance and construction scheduling, and coordination among aircraft and airport operators and the air traffic control management has not always occurred to the extent that the delay consequences of construction activities have been minimized.

6. Aircraft Demand

Aircraft demand refers not only to the number of aircraft seeking the use of an airfield but, often more importantly, the manner in which these aircraft are distributed by such factors as size, the time access is sought, arrival or departure, and sequence of aircraft type within the queue awaiting service. The nature of the distribution of aircraft may be unique to each major airport and must be understood to analyze capacity and delay. For example, simplistically, all airports can be divided into two broad generic classifications:

- Origin/Destination; and
- Connecting

Origin/destination airports are characterized by large percentages of passenger traffic either starting or ending their trip at the city served by the airport. Some of the passengers may be making connections and there may be connecting traffic between commuter airlines and larger air carriers, but this represents a relatively small proportion of the total traffic.

Connecting airports, on the other hand, are typified by a relatively large percentage of passengers transferring between aircraft. This connecting complex role manifests itself in a demand pattern which tends to bunch arrivals and departures in blocks, providing the capability to interchange connecting passengers in a high level of activity during the hours of the day which provide access to the various markets served with reasonable arrival and departure times. The existence of a connecting complex, with its attendant delay problems, provides benefits to the extent that:

- o An otherwise uneconomical level of service to many communities, large and small, is provided by means of through planes and connecting schedules.

- o The total level of operations is less than would otherwise be required to carry passengers and cargo between many city pair markets.

An extreme example of a connection operation is Atlanta's Hartsfield International Airport, as shown in Figure 8 on page 51. On an hourly basis, operations alternate between predominantly arrivals or departures. For a given level of demand, and a given runway configuration, the relative mix of arrivals and departures will have an effect on the level of delay encountered.

The six categories of factors described above interact dynamically and make the efficient use of a busy airfield a very complex task. It also makes the consideration of improvements to an airfield a potential exercise in futility, since a modification in one factor with the intent of increasing capacity may be thwarted by the constraints of other factors. The variety and interaction of factors affecting capacity result in both capacity and aircraft demand increasing or decreasing throughout the day, and traffic density will naturally vary from instant to instant. Delays result when traffic density reaches too high a level, so it is important to be aware of the very dynamic nature of traffic density. Delays occur when traffic density is low, also, but the more costly delays resulting from high traffic density levels are the appropriate subject of policy analysis. Chapter III includes statements and tests of hypotheses regarding the occurrence of delays.

D. Delay Measurement

There are four currently or potentially available sources of delay data: National Airspace Command Center, Performance Measurement System, Standard Air Carrier Delay Reporting System, and the FAA's Office of Systems Engineering Management. These are discussed below.

1. <u>National Airspace Command Center (NASCOM)</u>

About sixty airports report on a daily basis their delays of 30 minutes or longer. These data are received at NASCOM and maintained by the FAA's Air Traffic Service. The data include a beginning and ending time for each series of delays, the number of delays during that period, and a primary and secondary cause of delays for that period. The determination of a NASCOM delay is, in practice, a subjective decision of the controller. The quality of reporting is subject to the variation in controller workload.

These data are readily available in a computer data base and provide a very broad view of serious delay problems. Their lack of precision limits their use in analyzing delay causes, but they may provide an immediate ability to monitor delay trends at a large number of airports.

2. <u>Performance Measurement System (PMS)</u>

The Air Traffic Service also maintains, but not on computer, records of delays received through the PMS. These delays are officially described as being 15 minutes or longer but in practice shorter delays may be included. The definition and reporting of PMS delays are subject to the same constraints as NASCOM delays. The number of delays and airport conditions are reported by hour by about twenty airports.

3. Standard Air Carrier Delay Reporting System (SDRS)

Eastern Air Lines, American Airlines, and United Air Lines report delay data for about thirty specific airports as well as their entire systems to the FAA's Office of Aviation Policy and Plans (APO). See Appendix A for a list of the airports for which specific data are available. About 13 percent of all domestic air carrier operations were included in this reporting system for 1980. The delays are sorted by phase of flight and are in a computer data base. The causes of delays are not included, but the data provide a relatively detailed means of monitoring delay trends. The definition of a delay is based on a nominal standard for ground time and on computer-projected flight time. The types of delay measured, and their definitions are:

- Taxi-Out Delays--Determined by measuring the difference between actual taxi-out time for an aircraft and a preselected standard for each aircraft type and airport. The standards developed were based on the first ten percentile time of taxi-out distributions considering one complete year's worth of operations for each aircraft type at each airport. Where experience for particular aircraft types at airports did not exist, a time relationship was developed and extrapolated from those airports where multiple equipment types were operated. In no case was a standard (as a minimum) to be less than three minutes.

- Taxi-in Delays—Determined the same way as taxi-out delays, except that the minimum standard for any equipment type at any airport would not be less than two minutes.

- Airborne Delays—Computed as the difference between actual airborne time (off-to-on time) and each respective air carrier's computer flight plan airborne time, when it exists. The computer flight plan time considers winds and temperatures aloft (thus nullifying their variability), has an allowance for vectoring in the terminal areas, and is, by policy of each air line, the route/altitude to be flown. Some routes of low stage length do not have a computer flight plan. In these cases, a standard airborne time was developed based on a linear regression relationship of airborne time dependent upon route miles as determined from actual, uncongested airborne experience by equipment type.

- Gate Delay Measurements—Are derived from each carrier's delay code reporting system, wherein delay times at the gate and delay codes (signifying the reason) are input by airport personnel. In the Standard Air Carrier Delay Reporting System, gate delays are reported for (1) ATC clearance, (2) weather, (3) ramp congestion, and (4) flow control.

4. OSEM System

The FAA's Office of Systems Engineering Management developed a method of monitoring delay trends at airports, using CAB data on operational times actually experienced by air carrier flights. These data provided monthly estimates of the flight times between major airports for the years 1972 through 1977 [3]. An arbitrary standard flight time was subtracted to establish estimates of delays, and the results were used to detect trends in delays.

Of the readily available sources of delay data, only the air carrier reporting system (SDRS) employs a standard of minimum flight time and systematically reports deviations from the standard.

III. ASSESSMENTS OF AIRFIELD AND AIRSPACE CAPACITY AND DELAY

A. Airfield Capacity and Delay

The literature on capacity and delay suggests the following three hypotheses about the nature of terminal area aircraft delay:

- A certain minimum level of delay will probably be encountered at every airport. Queuing occurs because the delivery rate of departing and arriving aircraft seeking access to runways varies, and it cannot be expected to exactly match runway availability. When the demand for service exceeds capacity, albeit for a very short period, delay occurs.

- As the number of aircraft seeking runway access approaches the practical capacity of an airport's runways, the level of delay encountered at that airport, on the average, must increase. The queuing process, when combined with high traffic density, tends to pass delays on to subsequent flights so long as traffic density remains high.

- Disruptive weather conditions, either separately or in combination with high traffic density, must result in an even higher average level of delay. This is caused by the scheduling of operations according to the capacity available under good weather conditions.

Therefore, the major U.S. airports can be expected to exhibit a spectrum of average delays, depending on the practical capacity of the runways, the demand for runway access, and the weather. This is a simplified description of the capacity and delay situation with respect to runways and provides a useful framework for assessing current and future delay situations. For a more detailed discussion of individual factors see Chapter II.C.

The majority of this analysis is based on the SDRS data described in Chapter II.D.3. Although these data provide much detailed information about delays, they cannot be used to answer every important question that exists about delays. The SDRS data do provide a means of measuring the trend of delays from period to period and a means of comparing the relative severity of the delay problem among major airports. The SDRS data may also be used to approximate systemwide delays and the cost of such delays. Such approximations of delay costs are necessary in deciding whether to assume the costs of delay reduction projects.

1. Past Trends

Estimates constructed of average monthly delay for a composite of the 50 major air routes [3] revealed no increase in delay between 1972 and 1977, the only years for which these data are available. Both SDRS and NASCOM data indicate that delay has been increasing since 1976, until 1980.

This suggests a link between delay and number of operations, since U.S. air carrier operations also increased since 1976, until 1980.

Table 3 provides SDRS estimates of trends in delay by phase of operation from 1976 to 1980, as well as total air carrier operations.

TABLE 3

DELAY BY PHASE OF OPERATION

Phase of Operation	Average Delay per Flight, Minutes				
	1976	1977	1978	1979	1980
Gate Hold	.31	.47	.54	.60	.49
Taxi-Out	4.46	4.51	4.78	5.06	5.10
Airborne	4.28	4.27	4.36	4.40	4.13
Taxi-In	2.16	2.23	2.41	2.57	2.43
Average per Operation	5.61	5.74	6.05	6.32	6.08
Total Air Carrier Ops. (millions)	9.34	9.77	10.06	10.41	10.15

NASCOM delay data do not provide a measure of the amount of delay, such as total minutes, but rather tabulate the number of operations experiencing delays of 30 minutes or more. Information on the cause of delay is, therefore, limited to the most severe types of delays. Between 1976 and 1980, total operations delayed 30 minutes or more increased from 36,000 to about 58,000. Delays also increased relative to the number of operations, from 3.4 to 5.1 delays per 1,000 operations.

While total NASCOM reported delays have been increasing, there have been no dramatic changes in the causes of NASCOM delays. Data for recent years are summarized in Table 4. The predominant cause has been adverse weather, accounting for three-fourths or more of the delays each year.

TABLE 4

NASCOM DELAYS

	1976	1977	1978	1979	1980
Total Delays	36,196	39,063	52,239	61,598	57,554
Weather	76%	83%	79%	84%	78%
Equipment Failures	4%	2%	7%	3%	4%
Weather & Equipment Failures	11%	5%	3%	4%	6%
Runway Closures Due to Construction	1%	3%	3%	3%	3%
Volume	5%	2%	5%	4%	4%
Other Causes	3%	4%	3%	2%	5%
Total Delays per 1,000 Operations	3.4	3.5	4.6	5.2	5.1

2. 1980 Distribution of Delays

SDRS mean delay, calculated from total observed delay and the total number of observed operations, was about 6.1 minutes per operation in 1980, ranging from 2.9 to 9.5 at individual airports. Mean departure delay (gate hold delay plus taxi-out delay) is about 5.6 minutes, and mean arrival delay (airborne delay plus taxi-in delay) is about 6.6 minutes. Additional delay characteristics can be inferred from the distribution of delays presented in Table 5. Since about

TABLE 5

1980 DISTRIBUTION OF GATE HOLD DELAYS, TAXI-OUT DELAYS, AIRBORNE DELAYS, AND TAXI-IN DELAYS EXPERIENCED BY AIR CARRIERS

Minutes of Delay	Percent of Operations			
	Gate Hold	Taxi Out	Airborne	Taxi In
0	96.9%	9.3%	38.0%	15.9%
1	0.4	10.9	7.9	25.5
2	0.3	13.9	7.9	23.0
3- 4	0.6	26.1	14.9	23.2
5- 9	0.6	26.7	19.7	9.6
10-14	0.3	7.9	6.8	1.6
15-19	0.2	2.9	2.3	0.6
20-24	0.1	1.2	0.9	0.2
25-29	0.1	0.5	0.5	0.1
30-44	0.2	0.5	0.6	0.1
45-59	0.1	0.1	0.3	0.0
60+	0.2	0.1	0.2	0.0
	100.0	100.0	100.0	100.0

Note: Percentages may not sum to 100.0 due to rounding.

97 percent of departures suffer no gate hold delay, it can be inferred from the taxi-out distribution that about 60 percent of departures experience delays less than 4.0 minutes. A conservative estimate can be made that about 64 per~~ ~~t of arrivals experience taxi-in delays of less than 2.0 minutes.

Figure 6 portrays a distribution of delays inferred from the 1980 SDRS data.

FIGURE 6

1980 DISTRIBUTION OF DELAY DURATION

The distribution of delays has two noteworthy characteritics. One is the preponderance of delays of short duration—5 minutes or less. The other is the skewness of the distribution, with perhaps 1/2 of 1 percent of operations delayed more than one hour. (This last number is higher than the national average because the SDRS data are heavily weighted by airports which suffer the greatest numbers of long delays.)

The lowest mean delay at any reported airport (Cincinnati) is 2.9 minutes per operation. Mean delays for a sample of airports operating significantly below capacity are presented in Table 6. The measure of capacity used is practical annual capacity (PANCAP), a measure specified in FAA AC 150/5060-3A, as calculated by APO. PANCAP estimates runway capacity based on configuration, approximate aircraft mix, and an assumed 90 percent incidence of VFR conditions. As a rule, the PANCAP estimates have been noted to underestimate the capacity of a runway system to handle operations without serious delays.

TABLE 6

MEAN DELAY, OPERATIONS, AND CAPACITY
AT SELECTED AIRPORTS

Airport	1980 Mean Delay	FY-1980 Operations	PANCAP
Detroit (DTW)	4.0	268,240	475,000
Tampa (TPA)	4.2	237,244	355,000
Baltimore (BWI)	4.2	222,673	310,000
Dulles (IAD)	4.3	170,173	390,000

Table 6 indicates that while all the four subject airports operated well below PANCAP, the SDRS data indicate a mean delay of at least 4 minutes. Lack of capacity does not appear to be the cause of the delay. Exceptionally bad weather cannot be blamed either. Tampa (TPA), for example, reports a trivial number of NASCOM delays, which are delays of 30 minutes or longer generally associated with bad weather. The evidence suggests three conclusions: (1) some delay reported by SDRS is attributable to the en route system, (2) there is an upward estimation bias in SDRS delay estimates, and/or (3) a certain mean delay may be encountered at any airport as a result of the randomness of arrivals or departures and other minor constraints imposed by imperfect coordination of all phases of the departure or arrival process.

Table 7 presents a summary of the 1980 mean delay at every airport which accounts for over one percent of air carrier enplanements and which is included in the SDRS data. The twenty-three airports are ranked by mean delay. For each airport, the ratio of FY-1980 operations to PANCAP is also presented. This ratio presents a relative picture of average traffic density at major airports.

TABLE 7
MEAN DELAY AT SELECTED AIRPORTS

Airport	1980 Mean Delay (Minutes per Operation)	Ratio of 1980 Operations to PANCAP
Atlanta (ATL)	9.5	1.29
LaGuardia (LGA)	9.3	1.30
Kennedy (JFK)	9.2	1.15
O'Hare (ORD)	8.9	1.19
Denver (DEN)	8.1	1.37
Newark (EWR)	7.8	0.73
Boston (BOS)	7.2	1.13
St. Louis (STL)	7.2	1.20
Los Angeles (LAX)	7.1	1.19
National (DCA)	6.4	1.29
Miami (MIA)	6.0	0.95
San Francisco (SFO)	5.9	0.93
Pittsburgh (PIT)	5.9	0.61
Philadelphia (PHL)	5.9	1.13
Honolulu (HNL)	5.5	0.73
Dallas (DFW)	5.2	1.37
Houston (IAH)	5.2	0.97
Seattle (SEA)	4.7	0.77
New Orleans (MSY)	4.4	0.71
Cleveland (CLE)	4.2	0.84
Tampa (TPA)	4.2	0.67
Detroit (DTW)	4.0	0.56
Minneapolis (MSP)	3.3	0.79

San Francisco (SFO) is the median delay observation with a 0.93 ratio. Of the eleven airports with higher delay observations, only two had a ratio below 1.0, while of the eleven lower delay observations, only two ratios were above 1.0. The average ratio of the eleven higher airports is 1.16; the average ratio of the lower eleven is 0.83. Thus, the SDRS data demonstrate a trend of higher mean delays at airports with relatively high traffic density.

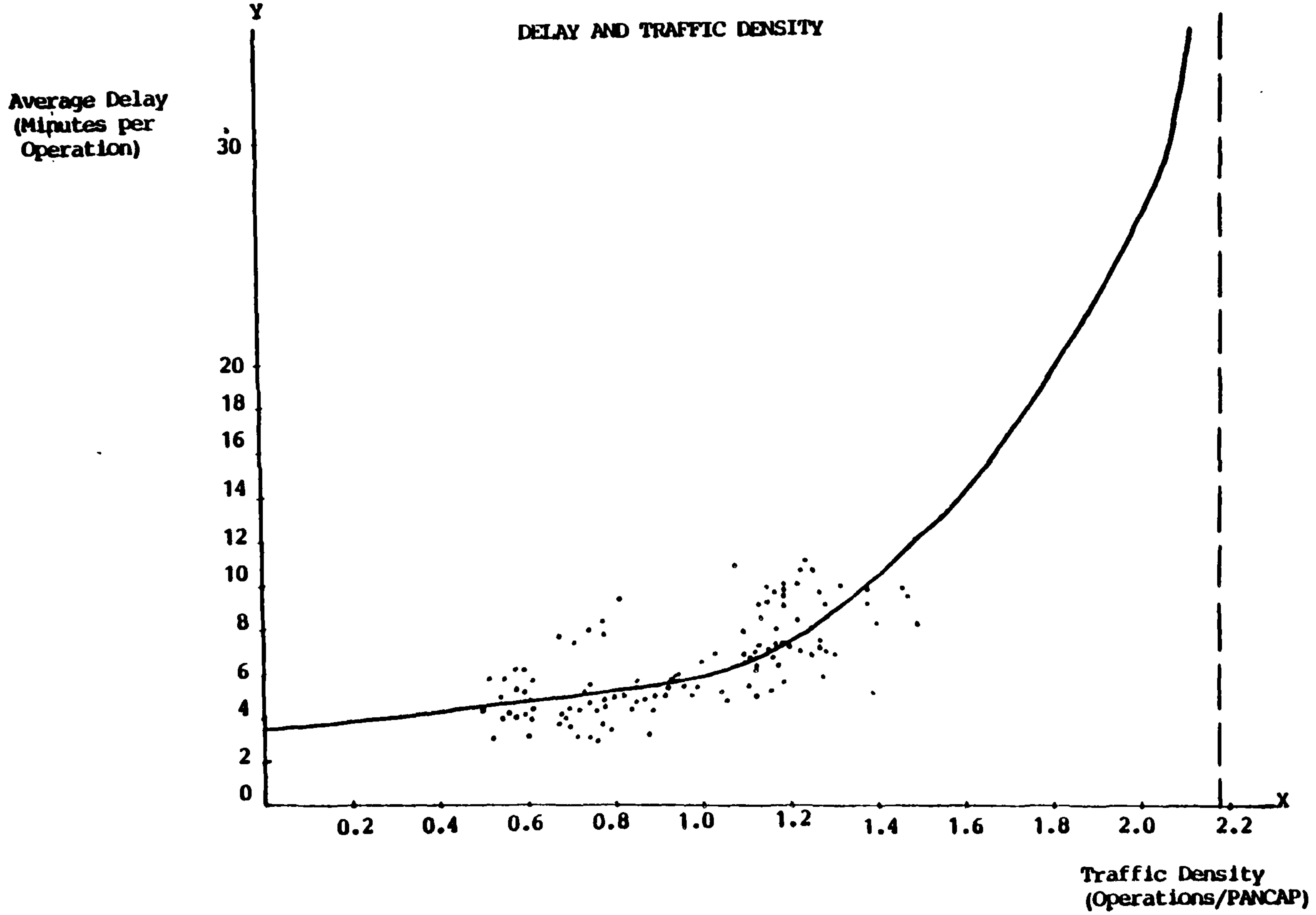
3. An Aircraft Delay Function

Figure 7 is a scatter diagram of annual average airport delays and associated ratios of annual operations to PANCAP for 1976 through 1980 for the 23 airports listed in Table 7. The diagram and the theoretical relationships summarized at the beginning of this chapter suggest that a function can be specified and estimated to predict average aircraft delay based on the utilization of runway capacity. Such a function should yield a relatively "flat" curve at low levels of utilization, reflecting the notion that major airports operating in the lower range of utilization are subject to some common, minimum level of delay, but are not subject to significant utilization-related delays. In the higher range of utilization, major airports are expected to experience increasingly higher levels of delay as their utilization increases. In fact, at some extremely high utilization level, the average delay at a major airport should be expected to reach a wholly unacceptable level.

FIGURE 7

ESTIMATED RELATIONSHIP BETWEEN

DELAY AND TRAFFIC DENSITY



The desired formula should better explain the variation in delay among airports if it contains variables for the degree of peaking at each airport, since peaking tends to exacerbate queuing delays, and weather.

Several functional forms, including linear, non-linear, and polynomial, were estimated. The equation:

$$Y = \frac{a\,X_2}{X_3(b - X_1)}$$

where: Y = average annual delay
X_1 = annual operations divided by PANCAP
X_2 = peaking factor
X_3 = weather factor

was selected because its properties are compatible with the theory of aircraft delay behavior and it was a relatively good fit to observed behavior. Three features of this function are worth n ting:

1. The function is monotonically increasing for all X between 0 and b, implying that delay increases with utilization.

2. The function is vertically asymptotic at X = b, implying that delay is indeterminate at some high level of utilization.

3. The function is positive and is approximately a/b at X = 0. Practically, the function is of little interest at relatively low levels of airport utilization. The value "a/b" is best understood as the minimum level of delay relevant to major airports.

The peaking factor is determined by calculating the air carrier operations scheduled during the three busiest hours of the day as a proportion of air carrier operations scheduled during the hours of 7:00 a.m. to 9:59 p.m. [1/] This proportion is normalized by dividing by the average proportion among all airports in the sample. The peaking factor ranges from a low of 0.83 at DCA to a high of 1.24 at JFK.

The weather factor is determined by taking the proportion of hourly weather observations which reflect conditions as good as or better than a 1500 foot ceiling and a 3 mile visibility, and then normalizing by dividing by the average proportion among all airports in the sample. [2/] The weather factor ranges from a low of 0.86 at LAX to a high of 1.14 at HNL. This factor does not incorporate the infinite variety of wind, precipitation, ice, and other weather conditions which affect delay.

Using observations from 1976 through 1980 for each of the 23 airports, the function was estimated using non-linear, ordinary least squares regression analysis as:

$$Y = \frac{7.00\ X_2}{X_3(2.13 - X_1)}$$

with: standard deviation of a = 0.63
standard deviation of b = 0.09
coefficient of non-linear correlation = 0.75
coefficient of non-linear determination = 0.56

1/ "Profiles of Scheduled Air Carrier Departure and Arrival Operations," DOT/FAA, November 1978.

2/ "Ceiling-Visibility Climatological Study and Systems Enhancement Factors," DOT/FAA, June 1975.

Displayed in Figure 7 is the estimated relationship between delay and traffic density when the peaking and weather factors are set equal to the average of 1.0.

The analysis of the relationship between delay and capacity utilization is subject to at least the following constraints.

1) The annual operations data do not reflect the diversity of aircraft types and the availability of runways for specific aircraft types.

2) The PANCAP estimates are based on a delay level of four minutes.

3) The SDRS data incorporate whatever en route delay may be experienced, and this delay may not be attributable to airport conditions. To this extent, SDRS data are overestimates of airport delays.

4) The definition of taxi delays is based on a standard performance measure which necessarily classifies about 90 percent of taxi operations as delays. Those who believe that such a standard is too restrictive would conclude that the SDRS data overestimate taxi delays. Taxi delays are also based on an average standard for all runways at an airport, which should lead to some overestimation of taxi delays.

The last two points, the possible inclusion of en route delay and the standard used for taxi delays, may account for much of the minimum delay reported at major airports through SDRS data.

4. The Impact of Weather on Delay

TABLE 8

FREQUENCY OF GOOD CEILING AND VISIBILITY CONDITIONS AT SELECTED AIRPORTS

Airport	Frequency	Airport	Frequency
ATL	85.5%	LGA	83.5%
BOS	83.8	MIA	97.6
CLE	84.9	MSP	88.5
DCA	88.5	MSY	89.1
DEN	93.5	ORD	83.7
DFW	91.6	PHL	84.3
DTW	85.9	PIT	82.9
EWR	83.2	SEA	83.7
IAH	85.4	SFO	84.5
JFK	84.5	STL	88.3
LAX	74.3	TPA	93.3

Source: "Ceiling-Visibility Climatological Study and Systems Enhancement Factors," prepared for DOT by National Climatic Center, June 1975.

To thoroughly test a hypothesis regarding the effect of weather on delay requires information on at least three items: wind conditions, precipitation on runways, and ceiling/visibility conditions. Data are readily available only for the last item. These statistics are presented in Table 8 for the twenty-three airports where enplanements equal or exceed 1 percent of national enplanements and which are included in the SDRS data (same airports as listed in Table 7). These data were used in calculating the weather factor included in the estimation of the delay function in the previous section. The inclusion of that factor did improve the explanatory capability of that function.

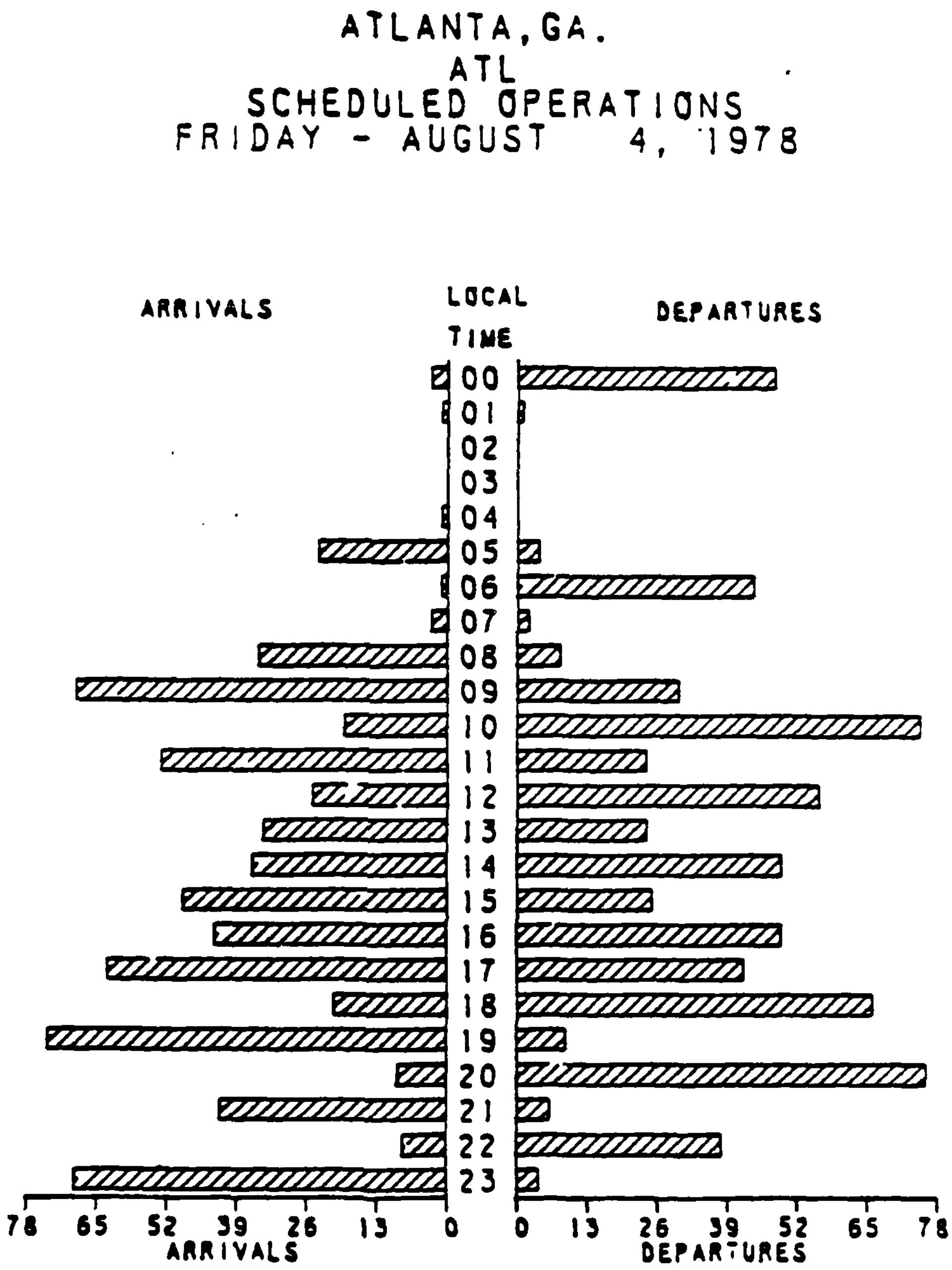
Another means of evaluating the impact of weather is through NASCOM data. These delays of 30 or more minutes indicate airports which suffer the greatest number of severe delays, usually weather-related. If weather is a significant factor in creating delays, one would expect the major airports that experience a relatively large number of NASCOM delays to also display a relatively high mean SDRS delay. In fact, the five top airports in terms of number of NASCOM delays are the five top airports in terms of mean SDRS delay for 1980. This corroborates the notion that, among major airports with high traffic density, airports with relatively bad weather will experience worse average delays.

5. The Tolerability of Delays

A certain level of delay is apparently inevitable at each major airport. This delay results from the randomness of demand for runway access and from weather. Delays above this minimum level are a cost of increasing operations levels, and the market for air transportation has demonstrated its willingness to tolerate higher levels of delay in order to increase operations levels at certain sites and times. For example:

a) Air carriers may be willing to assume higher delay costs in order to facilitate passenger connections. Consider activity at Atlanta, a major transfer hub. Figure 8 is a summary of departures and arrivals on a typical day in 1978 at Atlanta. There is a pattern of an hour predominated by arrivals followed by an hour of mostly departures, such as in the 0900-1000 pair, the 1100-1200 pair, the 1700-1800 pair, and the 1900-2000 pair. Any hour devoted mostly to arrivals increases the risk of delays (see Chapter II. C.); but the delay costs inherent in such a scheduling system are apparently tolerable to the air carriers which schedule their operations purposefully to facilitate connecting flights. See Appendix B for a detailed analysis of the Atlanta data.

FIGURE 8


ATLANTA, GA.
ATL
SCHEDULED OPERATIONS
FRIDAY - AUGUST 4, 1978
ARRIVALS
LOCAL TIME
DEPARTURES
00
01
02
03
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06
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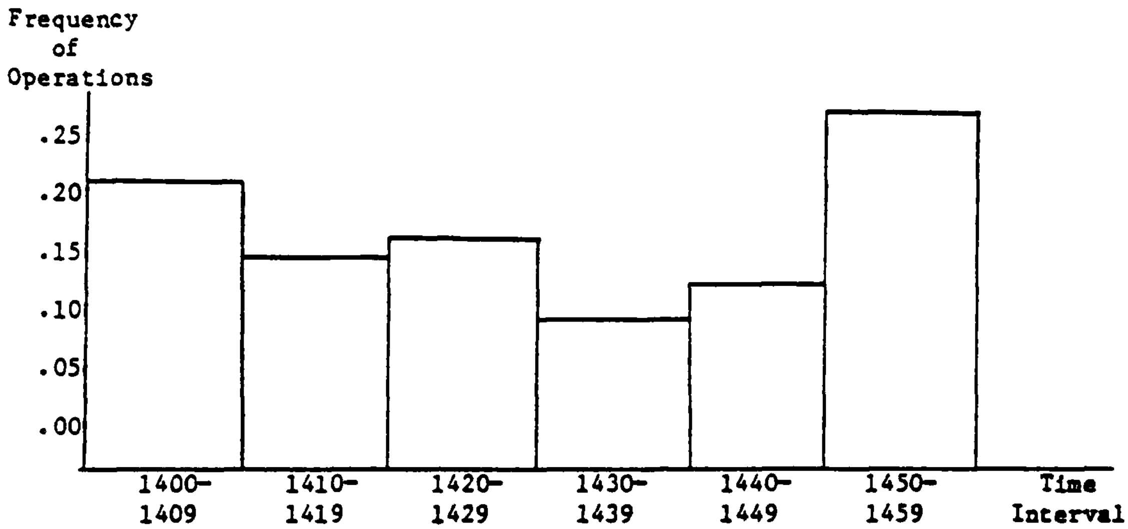
23
78 65 52 39 26 13 0
0 13 26 39 52 65 78
ARRIVALS
DEPARTURES

b) Passengers and air carriers may be willing to accept longer delays in order to accommodate passengers' scheduling desires. It has been noted that a disproportionate number of flights are often scheduled around the beginning of an hour. This is exhibited for O'Hare in Figure 9.

FIGURE 9

FREQUENCY DISTRIBUTION OF OPERATIONS AT
O'HARE INTERNATIONAL AIRPORT, THURSDAY, MAY 1980, 1400-1459



Air carriers have also reacted to increasing delays by creating additional points for passenger connections. Memphis (MEM) has seen an increase in air carrier operations from 106,000 in 1976 to 143,000 in 1980; this is a 35 percent increase compared to a nationwide increase of 9 percent.

The nature of delay appears to be unique to each airport, depending on the traffic density, the weather, and the set of market forces existing at each airport. Where relatively high delays appear to exist, the delays are tolerated because they are the result of, for example, scheduling convenience, passenger convenience, and exceptionally bad weather which cannot be overcome under present technology.

6. Estimates of Systemwide Delay and Delay Cost

SDRS data on average delays at major airports were presented earlier in this chapter. These data are based on samples of airport operations which do not vary substantially from year to year, thus permitting use of the raw data to detect airport and systemwide trends from year to year. However, the raw delay data for individual airports must be weighted by the actual number of operations at those airports in order to more correctly estimate systemwide delay. The number of air carrier operations conducted in 1980 at the airports reported by SDRS was 6,012,005. This represented about 59 percent of the 10,148,956 total air carrier operations conducted in 1980 at U.S. towered airports. Nearly all of the airports omitted from SDRS operate well below PANCAP, so a proxy for the average delay at all unreported airports can be constructed by taking the weighted average delay of all SDRS airports with a 1980 operations-to-PANCAP ratio less than 1.0. This weighted average delay for relatively underutilized airports is 4.9 minutes per operation. Using this as the average delay for all towered airports not reported by SDRS, it may be concluded that the systemwide average delay, using 1980 operations as weights, is 5.9 minutes per operation as reported by SDRS.

Estimates of delay cost are made for both ground and airborne delays under SDRS. These costs for 1976 through 1980 are summarized in Table 9. The overall average is calculated by weighting the two delay cost categories by their proportion of occurrence.

TABLE 9

SDRS DELAY COSTS

Year	Ground Delay Cost per Hour	Airborne Delay Cost per Hour	Overall Delay Cost per Hour
1976	$ 763	$1005	$ 858
1977	844	1156	965
1978	847	1204	982
1979	908	1301	1052
1980	1152	1847	1398

It is possible that the aircraft and routes flown by the three airlines reporting SDRS data are not typical. Given the wide variance in operating costs among aircraft types, for example, the SDRS cost data could be substantially different from the national average. This possibility was analyzed by calculating the 1980 variable cost per airborne hour for each aircraft type as reported by all air carriers, weighting each cost by the number of 1980 departures performed by that aircraft type, and calculating a weighted average variable cost per airborne hour.[1/] This 1980 average cost is $1820 per airborne hour, nearly the same as the $1847 reported by SDRS. Because ground as well as airborne delay costs are reported by SDRS, and because the SDRS airborne cost is corroborated by the data from all carriers, the overall delay cost per hour of $1398 listed in Table 9 is taken as an accurate representation of 1980 delay cost.

1/ "Aircraft Operating Cost and Performance Report," Civil Aeronautics Board, July 1981.

In the strictest sense, the cost of delay is the difference between actual operations costs and the theoretical costs of continuously efficient operations. That is, any cost which would not have been incurred had every operation run perfectly is a delay cost. The estimate of such cost is little more than a matter of curiosity, however, since it is neither a measure of the delay problem nor a useful tool for decisionmaking. The point has already been made that, for example, some delays are the unavoidable result of queuing, some delays are the result of airline scheduling decisions, and some delays are necessitated by bad weather. Estimating the cost of all such inefficiencies in the airline industry simply provides an exaggerated upper bound for total delay cost. Assuming the 5.9 minute average for systemwide delay per operation in 1980, when there were 10,148,946 air carrier operations, the upper bound for delay cost is an estimated $1.395 billion.

A more useful cost estimate than this upper bound is one which estimates delay problems subject to control by the FAA, airlines, or other interested parties. This estimate may more accurately serve as a decisionmaking tool in gauging the benefits of options to reduce delays. Such an estimate is calculated below by deducting estimates of minimum, unavoidable queuing delays and severe weather delays from the upper bound estimate of $1.395 billion.

Queuing delays have been noted earlier as a necessary evil of any airport system. These queuing delays may be expected to appear in the SDRS data as taxi-out (departure queue) and airborne (arrival queue) delays. Also, it was noted earlier that the definition of taxi standard times in the SDRS system probably leads to a minor overestimation of taxi delay. It is, therefore, appropriate to identify a small segment of queuing delay and deduct it from the upper bound estimate. An estimate of such queuing delay, the smallest one possible given the SDRS reporting constraints, can be made by defining the first minute of taxi-out and airborne delay as reported under SDRS as an average, necessary queuing delay. This results in 258,495 less hours of delay, approximately $0.361 billion less delay cost.

A conservative estimate of severe weather delays may be estimated by using both SDRS and NASCOM data. Approximately 11.5 percent of SDRS delay hours are represented by delays of 30 minutes or more. According to NASCOM, about 80.5 percent of delays of 30 minutes or more are caused by severe weather. Thus, at least 9.3 percent of all delay hours may be attributed to severe weather. This amounts to 92,812 less hours of delay, approximately $0.130 billion in delay cost.

Deducting these estimates of queuing delays and severe weather delays, the resulting estimate of delay is $0.904 billion. This estimate may more closely approximate that cost of delay which can be affected by delay reduction efforts. It must be further recognized that the ability to reduce this delay already exists. The scheduling practices of airlines which lead to: (1) disproportionate use of airports for connections; (2) disproportionate use of hours for total operations: (3) disproportionate blocks of operations within an hour; and (4) disproportionate grouping of arrivals and departures are examples of conscious decisions within the industry to accept increased delays, apparently because the cost of such delays is outweighed by the ensuing benefits. If airport capacities were increased to alleviate such delays, the result could be a net increase in delays, because airlines could simply continue their present scheduling practices on a larger scale.

7. The Future

Forecasting future capacity and delay in the airport and airway system is a perilous task. Most recently, the introduction of larger aircraft as well as slower than forecasted demand growth have combined to prevent a severe delay 1/ problem that was expected to exist by the early 1980's. Some uncertainties which affect current forecasts are:

- The effect of rising costs, especially fuel costs, on demand.
- The growth of small airlines under deregulation, which tends to:
  - Increase the frequency of flights into hubs from small communities.
  - Extend the work life of small commercial aircraft as they are sold off by the larger carriers and are pressed into service by the new entrants.
- The possible imposition of local community constraints on aircraft operations due to noise standards.

1/ There have been several times since the inception of commercial aviation in the United States when dire forecasts were made of future capacity delay problems. Immediately following World War II, advances in aircraft design were not matched by airport development and delays and crowded terminals were common. Advances in navigational aids and Federal airport development financing alleviated the problem. Enplanements grew dramatically between 1957 and 1963, but traffic remained manageable because the introduction of jets increased seating capacity such that there was no increase in the number of air carrier operations. Congestion experienced in the late 1960's resulted in airport expansion and longer hours of operation. Based on forecasts of future demand, however, it was believed that capacity would be soon overwhelmed. The expected large increase in air carrier traffic failed to materialize.

The following analysis of the future concentrates on the top thirty-nine airports (in terms of 1979 enplanements), accounting for over 75 percent of enplanements. These thirty-nine airports, listed in Table 10, include the top twenty-nine airports in terms of air carrier operations and the top twenty airports in terms of mean delay as reported by SDRS.

Table 10 also contains FAA forecasts of individual airport activity (taken from Terminal Area Forecasts, Fiscal Years 1981-1992 [41]). Total operations for the 39 airports are forecast to rise 31 percent between 1980 and 1991, an average annual rate of increase of 2.5 percent. Total operations at all towered airports in the United States are forecast to increase 34 percent or an average annual rate of 2.7 percent for the same period. An estimate of the 1991 weighted average delay per operation was constructed using forecasts of 1991 operations, estimates of current airport capacity (PANCAP), and the apparent functional relationship between delay and the ratio of use-to-capacity. Average systemwide delay is forecast to increase from 5.9 minutes in 1980 to 8.7 minutes in 1991. Valuing delay at 1980 unit costs and extrapolating to a total system basis, air carrier delays would have an upper bound cost of $2.7 billion per year by 1991. Deducting estimates of unavoidable queuing delays and severe weather delays, about $1.7 billion per year of this delay may be subject to control.

FAA airport activity forecasts do not always simply indicate demand for access to an airport, because the forecasts incorporate estimates of capacity constraints and limit terminal activity accordingly.

TABLE 10

TOP 39 AIRPORTS RANKED BY 1979 AIR CARRIER ENPLANEMENTS

Airport	Percentage of 1979 Air Carrier Enplanements	Cumulative Percentage	Total Operations 1980 Actual	Total Operations 1991 Forecast	Total Operations Percent Annual Growth
O'Hare (ORD)	6.85%	6.85%	734,555	757,000*	0.3%
Atlanta (ATL)	6.47	13.33	609,466	772,000*	2.2
Los Angeles (LAX)	5.69	19.02	534,414	562,000*	0.5
Kennedy (JFK)	3.95	22.97	311,777	375,000	1.7
San Francisco (SFO)	3.82	26.79	371,222	342,000*	0.0
Dallas-Ft. Worth (DFW)	3.42	30.21	467,139	612,000*	2.5
Denver (DEN)	3.01	33.22	485,695	573,000*	1.5
La Guardia (LGA)	2.85	36.07	319,891	302,000*	0.0
Miami (MIA)	2.79	38.86	376,820	438,000*	1.4
Boston (BOS)	2.31	41.17	340,896	516,000	3.8
National (DCA)	2.20	43.37	354,717	381,000*	0.7
Honolulu (HNL)	2.15	45.52	385,463	525,000	2.8
Detroit (DTW)	1.77	47.29	268,240	348,000	2.4
St. Louis (STL)	1.74	49.03	336,560	376,000*	1.0
Houston (IAH)	1.67	50.71	290,443	501,000	5.1
Pittsburgh (PIT)	1.64	52.35	353,100	454,000	2.3
Las Vegas (LAS)	1.55	53.90	364,355	550,000	3.8
Seattle (SEA)	1.51	55.41	216,418	319,000	3.6
Minneapolis (MSP)	1.49	56.90	284,572	363,000	2.2
Philadelphia (PHL)	1.47	58.37	334,683	467,000*	3.1
Newark (EWR)	1.40	59.77	204,324	289,000	3.2
San Diego (SAN)	1.29	61.07	155,914	235,000	3.8
Cleveland (CLE)	1.16	62.23	247,286	319,000	2.3
Tampa (TPA)	1.15	63.37	237,244	336,000	3.2
Phoenix (PHX)	1.11	64.48	390,464	471,000	1.7
New Orleans (MSY)	1.00	65.48	198,515	270,000	2.8
Kansas City (MCI)	0.99	66.47	184,301	265,000	3.4
Orlando (MCO)	0.95	67.42	157,535	199,000	2.1
Ft. Lauderdale (FLL)	0.91	68.32	284,544	382,000	2.7
San Jose (SJC)	0.83	69.15	415,543	647,000	4.1
Memphis (MEM)	0.82	69.97	337,603	575,000	5.0
San Juan (SJU)	0.74	70.72	191,151	343,000	5.5
Salt Lake City	0.68	71.40	285,104	436,000	3.9
Portland (PDX)	0.68	72.08	219,404	306,000	3.1
Oakland (OAK)	0.65	72.73	487,584	786,000	4.4
Sacramento (SMF)	0.61	73.35	170,733	208,000	1.8
Santa Ana (SNA)	0.56	73.91	569,779	632,000*	0.9
Baltimore (BWI)	0.56	74.47	222,673	353,000	4.3
Buffalo (BUF)	0.56	75.02	162,167	227,000	3.1
Total 39 Airports		75.02%	12,862,294	16,812,000	2.5%

* Activity constrained below demand for access.

Twenty-eight of the top 39 airports are not so constrained (see Table 10). The analysis considers these 28 airports first.

Based on the data of Table 7, it can be argued that experience suggests that a ratio of operations-to-PANCAP of 1.25 is tolerable (but not necessarily desirable) simply because it reflects present conditions at many busy airports. The average delay per operation is about 8 minutes for this ratio. Of the 28 airports under consideration, 20 have projected utilization ratios less than 1.25 through 1991 and are listed in Table 11.

TABLE 11

AIRPORTS WITH NO APPARENT DELAY PROBLEM THROUGH 1991

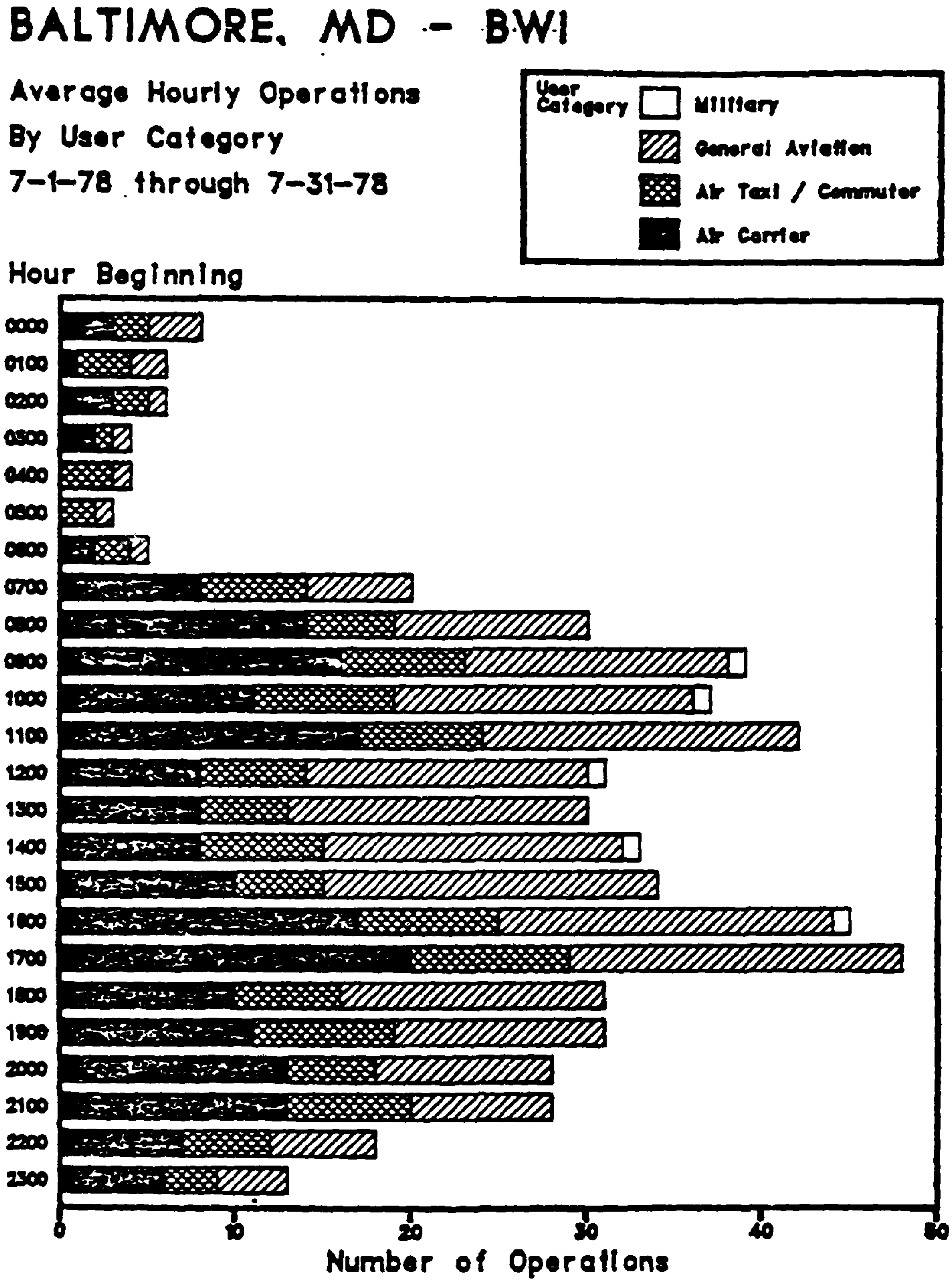
Airport	Forecasted 1991 Total Operations	PANCAP	Ratio of 1991 Operations to PANCAP	% Ops. In 3 Peak Hours 1978
Buffalo (BUF)	227,000	195,000	1.16	29.7
Baltimore (BWI)	353,000	310,000	1.14	32.4
Seattle (SEA)	319,000	280,000	1.14	26.7
Miami (MIA)	438,000	395,000	1.11	31.8
Cleveland (CLE)	319,000	295,000	1.08	24.9
Sacramento (SMF)	208,000	195,000	1.07	30.7
Kansas City (MCI)	265,000	250,000	1.06	27.3
Newark (EWR)	289,000	280,000	1.03	28.1
San Juan (SJU)	343,000	335,000	1.02	27.5
Salt Lake City (SLC)	436,000	430,000	1.01	26.4
Minneapolis (MSP)	363,000	360,000	1.01	29.1
Honolulu (HNL)	525,000	525,000	1.00	28.8
San Jose (SJC)	647,000	660,000	0.98	29.5
New Orleans (MSY)	270,000	278,000	0.97	23.7
Tampa (TPA)	336,000	355,000	0.95	25.1
Fort Lauderdale (FLL)	382,000	430,000	0.89	N/A
Pittsburgh (PIT)	454,000	580,000	0.78	25.2
Portland (PDX)	306,000	390,000	0.78	27.2
Detroit (DTW)	348,000	475,000	0.73	25.7
Orlando (MCO)	199,000	295,000	0.67	30.6

In order to gauge the reasonableness of the assertion that these twenty airports can handle their respective levels of forecasted operations in 1991, consider two extreme cases—Baltimore (BWI) and Newark (EWR). BWI has one of the highest ratio of operations-to-PANCAP, and EWR has the highest current mean delay among the twenty airports. According to Terminal Area Forecasts [41], about 41 percent of operations at BWI in 1991 are expected to be general aviation operations. A significant portion of the relatively high level of general aviation activity at BWI could be diverted or rescheduled if necessary to reduce future congestion impacting air carrier service (see Figure 10). As mentioned earlier, the currently high level of delay at EWR may be partially due to relatively bad weather. It may also be a necessary result of the relatively complex ATC environment in New York. As illustrated in Figure 11, however, EWR demonstrates a large amount of peak hour scheduling, and it is reasonable to assume that the forecasted increases in operations (not including any unexpected diversions from other NYC airports) can be accommodated if growth is funneled into off-peak hours.

One measure of the extent of peak hour scheduling is the percentage of scheduled operations between the hours of 0700 and 2159 which occur during the three peak hours. If the same number of operations were scheduled in every hour over the 15 hour period, the peak hour percentage would approach 20.0. The average for the thirty-six top airports for which data are available is 26.9 percent; EWR is the eleventh highest with 28.1 percent. 1/ For the twenty airports listed in Table 11,

1/ "Profiles of Scheduled Air Carrier Departure and Arrival Operations for Top 100 U.S. Airports," November 1978, Prepared by Transportation Systems Center for FAA.

FIGURE 10


BALTIMORE, MD - BWI
Average Hourly Operations
By User Category
7-1-78 through 7-31-78
User Category
Military
General Aviation
Air Taxi / Commuter
Air Carrier
Hour Beginning
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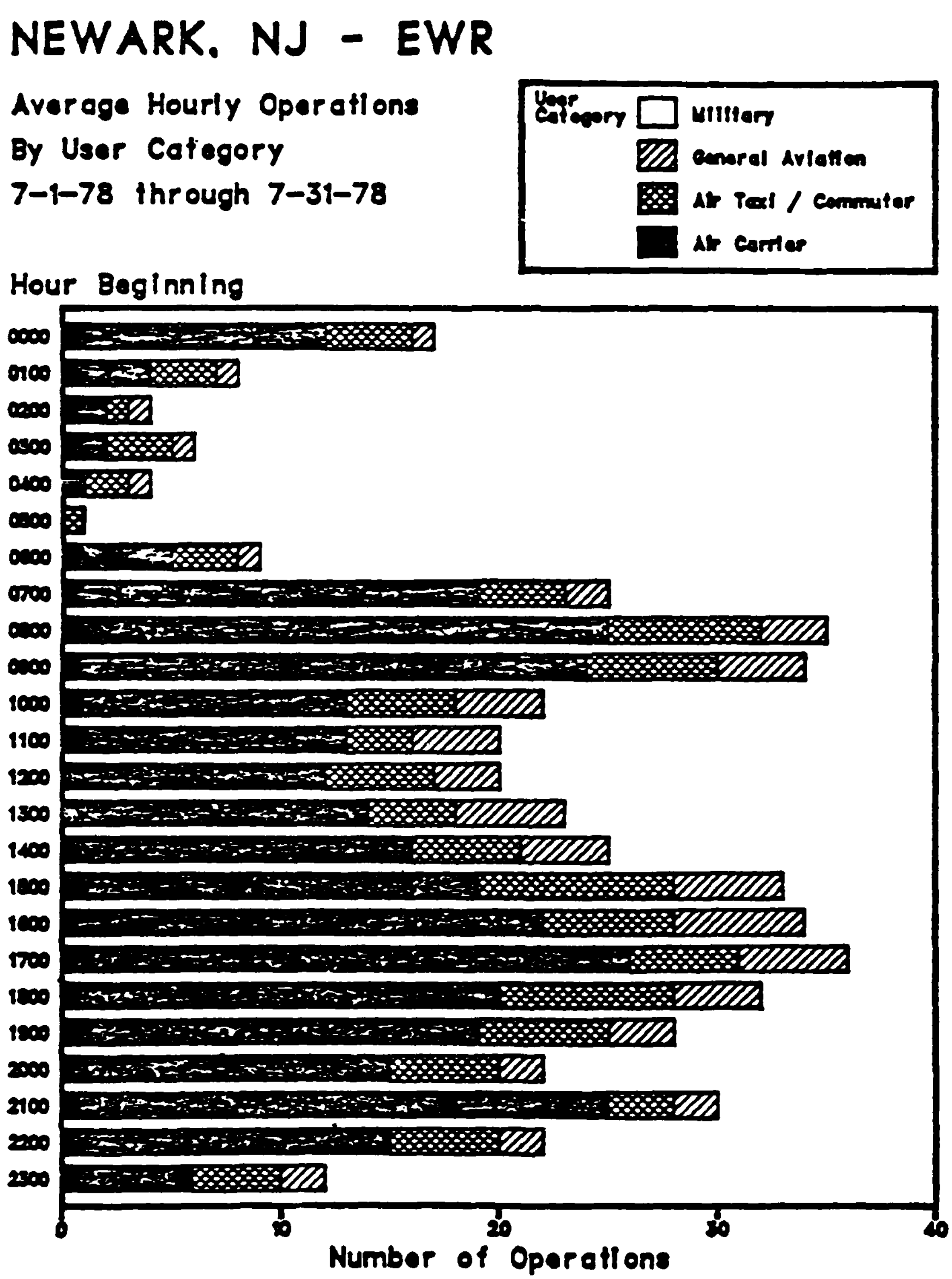
Number of Operations

FIGURE 11


NEWARK, NJ - EWR
Average Hourly Operations
By User Category
7-1-78 through 7-31-78
User Category
Military
General Aviation
Air Taxi / Commuter
Air Carrier
Hour Beginning
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0200
0300
0400
0500
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Number of Operations

seventeen have operations during the three peak hours which exceed 25 percent of total operations. If some congestion develops, it can probably be accommodated at these airports by increasing operations in off peak hours.

Excluding the twenty airports in Table 11, eleven of the top 39 airports are constrained by existing FAA forecasts and eight airports have high projected ratios of use-to-capacity. These airports all exhibit, to a varying degree, an inability to handle the level of operations likely to be demanded in 1991. The nineteen airports may be grouped into three categories--(1) airports with a high proportion of general aviation activity, (2) airports with nearby alternative facilities, and (3) airports with no apparent congestion relief.

The first category consists of airports where general aviation may play a significant role in creating congestion. For these airports, the ratio of nonconstrained forecasted 1991 operations to current PANCAP is no greater than 1.05 when operations are limited to air carrier, commuter, air taxi, and military operations. Data for the seven airports so defined are summarized in Table 12.

Actions which limit general aviation activity or increase the general aviation capacity at these seven airports and/or nearby airports probably would be sufficient to prevent congestion problems. General aviation

TABLE 12

AIRPORTS WHERE GENERAL AVIATION SIGNIFICANTLY AFFECTS POTENTIAL FOR CONGESTION

Airport	Forecasted Total 1991 Operations	Forecasted GA 1991 Ops.	PANCAP	Ratio of Non-GA Operations to PANCAP	% Ops in 3 Peak Hours 1978
Houston (IAH)	501,000	185,000	300,000	1.05	24.4
Santa Ana (SNA)	918,000 1/	565,000	385,000	0.92	N/A
Memphis (MEM)	575,000	287,000	355,000	0.81	30.1
Las Vegas (LAS)	550,000	296,000	330,000	0.77	28.0
San Diego (SAN)	235,000	98,000	180,000	0.76	22.5
Phoenix (PHX)	471,000	276,000	330,000	0.59	27.4
Oakland (OAK)	786,000	585,000	595,000	0.34	N/A

1/ Unconstrained Forecasts

activity at these airports may experience a relative decline as general aviation pilots divert to other locations of their own volition to avoid the higher traffic densities and increased air carrier traffic. While there is some peaking at the airports listed in Table 12, the potential benefit from redistributing traffic to off-peak hours is limited.

The second category consists of airports where a nearby airport offers potential congestion relief by handling a substantial number of air carrier, commuter, and air taxi operations. These airports are listed in Table 13. All four airports have relatively high traffic density throughout the entire day (low peaking factor), but vary as to the proportion of general aviation traffic using the facility.

TABLE 13

AIRPORTS WHERE CONGESTION RELIEF MAY BE OBTAINED
BY DIVERSION OF TRAFFIC TO OTHER LOCAL AIRPORTS

Airport	Forecast 1991 1/ Ops.	Forecast GA 1991 Ops.	PANCAP	Ratio of Non-GA Ops. to PANCAP	% Ops. in 3 Peak Hours 1978	Nearby Alternative Airport
San Francisco (SFO)	507,000	29,000	400,000	1.20	24.4	Metropolitan Oakland Int'l (OAK)
Dallas-Ft. Worth (DFW)	640,000	20,000	340,000	1.82	25.6	Dallas Love Field (DAL)
O'Hare (ORD)	1,025,000	60,000	616,000	1.57	23.7	Chicago Midway (MDW)
Washington National (DCA)	516,000	117,000	275,000	1.45	21.4	Dulles Int'l (IAD) Baltimore-Washington (BWI)

1/ Unconstrained forecasts, which represent potential demand and not actual activity.

In the case of San Francisco, local planning efforts already emphasize future increased utilization of OAK, along with a constraint on activity at SFO. Commuter activity may increase at DAL and MDW without government initiatives, somewhat easing the pressure on DFW and ORD, but either a significant diversion of air carrier activity from DFW and ORD or an expansion of capacity may also be required to provide tolerable conditions at these terminals. Existing runway capacity at DFW and ORD cannot be expected to accommodate projected levels of 1991 air carrier demand without major congestion at these airports. Both BWI and IAD can accommodate traffic diverted from DCA for congestion or environ- mental reasons.

The third category of airports consists of those for which no solution to congestion problems is apparent. They are listed in Table 14. Included are the New York airports, JFK and LGA, for which the nearby airport, Newark (EWR), does not offer sufficient relief. (If additional capacity is not realized, EWR can be expected to suffer severe congestion as a result.) Congestion at airports in this third category has the potential to degrade the overall capacity of the national air transportation system. Only JFK exhibits a large amount of peaking and, therefore, redistribution of traffic into nonpeak times may not alleviate future congestion problems.

TABLE 14

AIRPORTS REQUIRING ADDITIONAL CAPACITY BY 1991

Airport	Forecasted 1991 Operations 1/	Projected GA 1991 Ops.	PANCAP	Ratio of Non-GA Ops. to PANCAP	% Ops. In 3 Peak Hours 1978
Atlanta (ATL)	782,000	57,000	472,000	1.53	26.7
Boston (BOS)	516,000	75,000	303,000	1.46	24.9
Denver (DEN)	701,000	90,000	355,000	1.72	27.5
Los Angeles (LAX)	793,000	35,000	448,000	1.69	24.6
Philadelphia (PHL)	571,000	43,000	295,000	1.79	24.1
St. Louis (STL)	488,000	40,000	280,000	1.60	26.8
LaGuardia (LGA)	502,000	48,000	247,000	1.84	22.2
John F. Kennedy (JFK)	375,000	46,000	272,000	1.21	32.1

1/ Unconstrained forecasts, which represent potential demand and not actual activity.

As noted earlier, forecasts of demand have been inaccurate in the past, so it is worthwhile to consider the ramifications of some uncertainties affecting the forecasts used in the above analysis.

One uncertainty is the cost of fuel, which now represents over 40 percent of the direct operating costs for air carriers. The FAA forecasts given above incorporate average annual increases in fuel price in the area of 9 percent. Various scenarios can be imagined which would cause these increases to be significantly higher. However, the effect of such increases on the U.S. economy, and air transportation in particular, are quite difficult to predict. General aviation would likely exhibit less activity than forecasted, and this would help to avoid congestion for at least the seven airports listed in Table 12. It is possible that radically higher fuel prices or constraints on fuel availability would prevent all of the congestion problems forecasted above, but the probability of such an outcome is not high enough to ignore the actions required by the most likely projection of traffic.

Another uncertainty is the imposition of operations constraints by local governments to mitigate adverse environmental impacts. Such constraints would immediately cause a degradation of the capacity of national air transportation. While the imposition of constraints on airport operation has the beneficial side effect of reducing delay at the affected airports, the net impact is a loss in the ability to provide air service to travelers.

A third uncertainty is the effect of deregulation on future aviation activity. Current forecasts incorporate substantial growth in commuter activity (See Table 1), especially through 1984, by which year it is forecast that the commuter airline industry will have achieved maturity. This means that the number of commuters will have stabilized and that commuters will have replaced air carriers on nearly all appropriate routes. Commuter itinerant operations and instrument operations are projected to grow at annual rates of 6.5 and 6.9 percent, respectively, between 1980 and 1990. Air carrier growth for the same period is less than 2 percent. It is possible that the current forecasts for substantial commuter growth understate the future demand for commuters. A scenario can be imagined in which the frequency of commuter flights from smaller airports into the major airports increases dramatically (growth greater than the 6 to 7 percent growth forecast for the 1980's), placing additional strain on major airports. Such strain would especially affect the twelve airports listed in Tables 13 and 14, as well as the airports in Houston, Las Vegas, and Memphis.

Another possible impact of deregulation on airport congestion could be a movement away from aircraft with larger seating capacity. Current FAA forecasts incorporate the historical growth rate of about four seats per year in average aircraft seating capacity. This assumes that smaller jet aircraft will be phased out and replaced by larger jets. Since deregulation, however, several newly formed airlines have been using the smaller jets and extending their work life. This translates into more operations to handle the same number of passengers. Again, airports listed in Tables 13 and 14 would experience the greatest congestion impacts.

B. Airspace Capacity and Delay

There is apparent consensus among the FAA, the airline industry, and other segments of aviation that there is no en route capacity problem at this time, other than that caused by the temporary shortage of controllers due to the 1981 strike. This position rests on the belief that there are sufficient alternative routes between origins and destinations so that capacity will not be approached under current traffic levels. Nevertheless, delay is generated each time an aircraft is required to fly other than its optimum route. From the perspective of this study, an important consideration is the extent to which such delay occurs and its acceptability. Little data exist which can be used to directly analyze airspace capacity and delay.

1. Past Trends

LRS provides estimates of airborne delay (see Table 3). Airborne delay reported by SDRS, however, represents the impact of conditions at destination terminals as well as en route conditions. (See Chapter II.B.2. and Figure 2 for a description of the relationship between aircraft delay causes and experience sites.) Between 1976 and 1980, average airborne delay per arrival (from both terminal and en route causes) reported by SDRS decreased 4 percent from 4.28 to 4.13 minutes. During the same period, average ground delays per operation increased about 16 percent, en route traffic grew 26 percent, and itinerant terminal traffic increased 12 percent. Given that airfield delay is considered exponentially related to operations, it is unlikely that airborne delay attributable to airfield causes declined. Thus, delay caused by the en route environment may have actually decreased over the period 1976 through 1980.

Monthly averages of airborne delay for a composite of 50 major air carrier routes have been estimated and are given in Table 15. The estimates reveal no increase in delay between 1972 and 1977. (Note that the airborne delay measures from SDRS listed in Table 3 and those listed in Table 15 are not comparable because different trip time standards are used in estimation.)

TABLE 15

AVERAGE MONTHLY AIRBORNE DELAYS FOR A COMPOSITE OF 50 MAJOR AIR CARRIER ROUTES

Year	Delay (Minutes)
1972	9
1973	9
1974	11
1975	10
1976	9
1977	9

Source: Airline Delay Trends: 1972-1977, FAA-EM-78-11, U.S. Department of Transportation, July 1978.

Table 16 provides comparative statistics on the density of en route traffic. There is a wide range of annual IFR operations per square mile of center area. In 1980, New York Center had the highest density of traffic and Salt Lake City Center had the lowest density, 29.1 versus 2.7 annual IFR operations per square mile, respectively. During the past eleven years there has been no change in the relative dispersion of traffic among centers. 1/

TABLE 16

DENSITY OF EN ROUTE TRAFFIC
(ANNUAL IFR OPERATIONS PER SQUARE MILE)

Center Year	1969	1980	1992 Forecast
Boston	9.7	10.3	13.2
New York	25.6	29.1	40.9
Washington	11.2	15.8	23.0
Atlanta	13.5	21.7	31.9
Jacksonville	6.3	10.3	14.1
Memphis	6.6	13.5	20.6
Miami	8.4	14.3	21.0
Chicago	17.5	22.2	33.8
Cleveland	23.4	27.8	43.3
Indianapolis	14.3	20.7	32.2
Minneapolis	2.0	4.9	7.1
Kansas City	7.0	10.9	15.7
Albuquerque	3.7	7.3	9.3
Ft. Worth	7.7	12.0	17.7
Houston	6.1	9.3	14.4
Denver	2.9	5.0	7.4
Salt Lake City	1.1	2.7	3.7
Los Angeles	7.2	10.1	14.2
Oakland	7.8	11.5	14.6
Seattle	3.0	5.4	8.7

1/ The ratio of the variance of center traffic densities to average center density was .7 in 1969 and .6 in 1980.

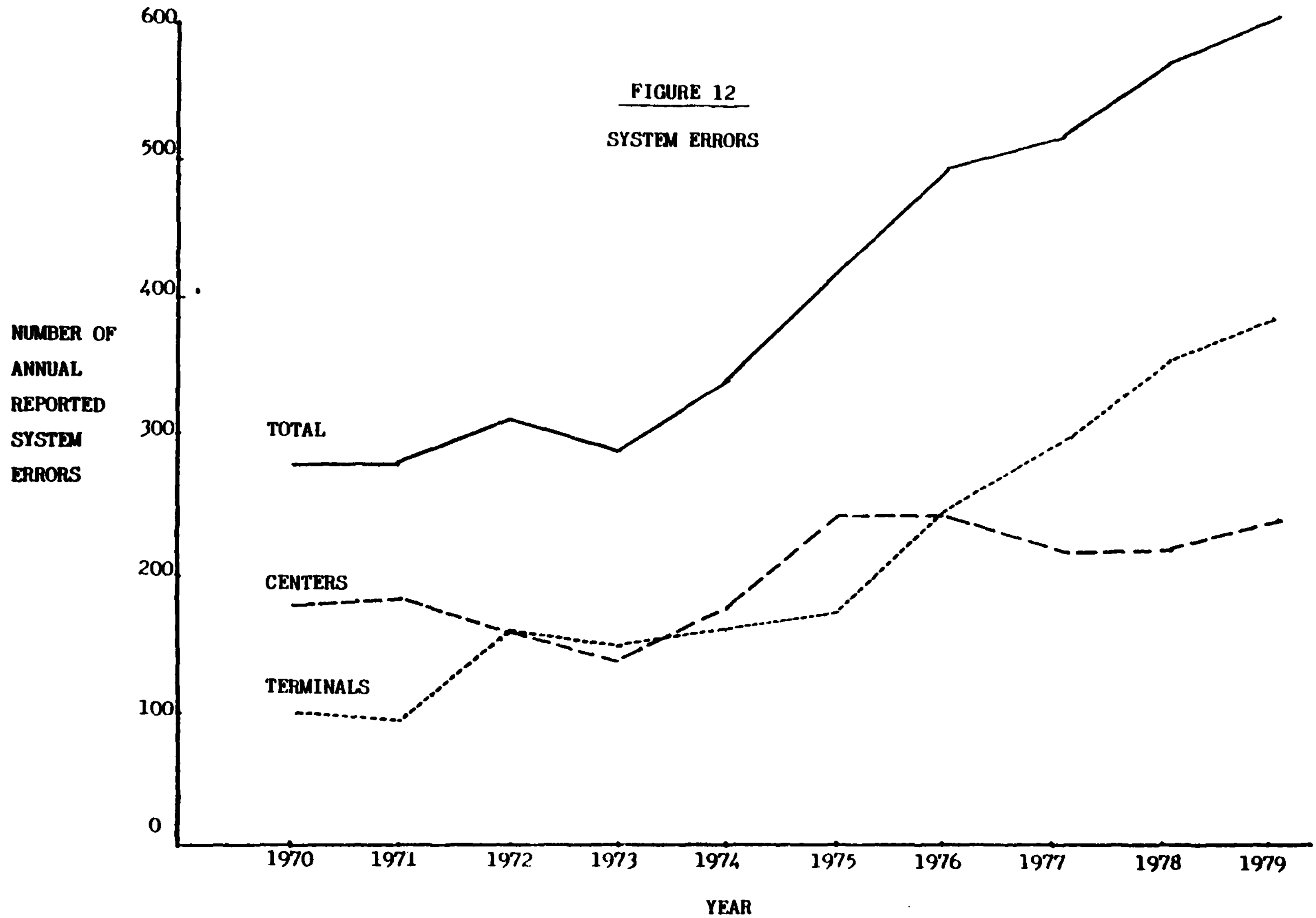
There are two potential indicators of en route congestion other than direct measurement of delay. One is the number of air traffic control (ATC) errors, where aircraft are provided air traffic service resulting in less than applicable separation minima between two or more aircraft or between the aircraft and terrain or obstacles. Intuitively, ATC system errors should be positively correlated with congestion.

Between 1970 and 1979, ATC errors increased from about 280 per year to over 610 [36], as shown in Figure 12. Almost all of this increase occurred in the terminal area; those errors originating en route increased from 190 to only 233 in nine years. The rate of en route system errors per aircraft handled dropped from 9 to 8 per million aircraft handled. During the same period, the rate of terminal system errors rose from 2 to 5 per million operations. The evidence points to no increase in en route congestion since 1970.

A second potential indicator of en route congestion is the assignment of suboptimal routings. FAA personnel maintain that assignment of suboptimal routings on well traveled routes is common. Frequently cited examples include traffic operating in the heavily populated northeastern U.S. and traffic operating near Wilmington, North Carolina, a very busy VOR on the New York to Florida route.

FIGURE 12

SYSTEM ERRORS



Source: "Report of the FAA Task Force on Aircraft Separation Assurance," FAA-EM-78-19.

Delay due to suboptimal routes, while undesirable, appears tolerable at the present time. Although airlines recognize this type of delay, an industry position paper stated that the en route control system generally handles the current volume of traffic without excessive delays (Airport and Airway Congestion [4, p. 12]). The paper notes that suboptimal routing (speed and altitude) produces higher fuel costs. This problem, however, is as much due to airline scheduling practices as it is to any shortcomings in the air traffic control system.

2. Current Situation

Airspace has a vertical as well as a horizontal dimension. Peak IFR traffic altitude data suggest that a substantial amount of en route airspace is relatively unutilized. The number of flights assigned to each cruising altitude by thousand foot increments during the year's busiest IFR traffic day are given in En Route IFR Air Traffic Survey Peak Day FY-1978. 1/ Because aircraft above 18,000 feet are required to fly IFR, traffic counts at these altitudes represent peak traffic irrespective of weather conditions. Traffic counts below 18,000 feet probably represent peak demand as produced by instrument weather. Much traffic at lower levels has the option of flying either IFR or VFR. Thus, the peak day represented by the data probably occurred on an IFR day and thus represents a "worst possible" case resulting from bad weather.

1/ These data were published annually for each ARTCC up to 1978.

Normally, the busiest altitude—usually a 1,000 foot segment between 5,000 and 10,000 feet— carries substantially more traffic than any other altitude, albeit primarily general aviation traffic. This altitude is either at or below a level of usage that generates tolerable delay from a user's perspective. (If delay was intolerable at this altitude, traffic would shift to other nearby altitudes where airspace usage is less.) From the perspective of available airspace, even if the busiest altitude was operating at maximum capacity, substantial additional traffic could be accommodated at other nearby altitudes currently carrying less traffic. Figure 13 demonstrates the amount of peak day operations carried in 5,000 foot altitude segments, for a representative en route center.

The capacity to accommodate additional traffic under existing technology can be measured by the difference between the actual volume of traffic at each altitude and the volume of traffic at the busiest altitude. A typical traffic distribution and demonstrated capacity by altitude are presented in Figure 14. 1/ Line BCDE represents maximum demonstrated capacity. As indicated, this level is either at or below true capacity. The area below line BCDE and the actual traffic frequency distribution is the amount of demonstrated additional available capcacity. At 29,000 feet, the vertical separation standard doubles, which cuts demonstrated capacity in half.

1/ Demonstrated capacity for 5,000 foot altitude segments was estimated by taking the number of operations for the busiest 1,000 foot segment and multiplying by 5.

Figure 15
Cleveland ARTCC Peak Day Operations
(FY-1978)

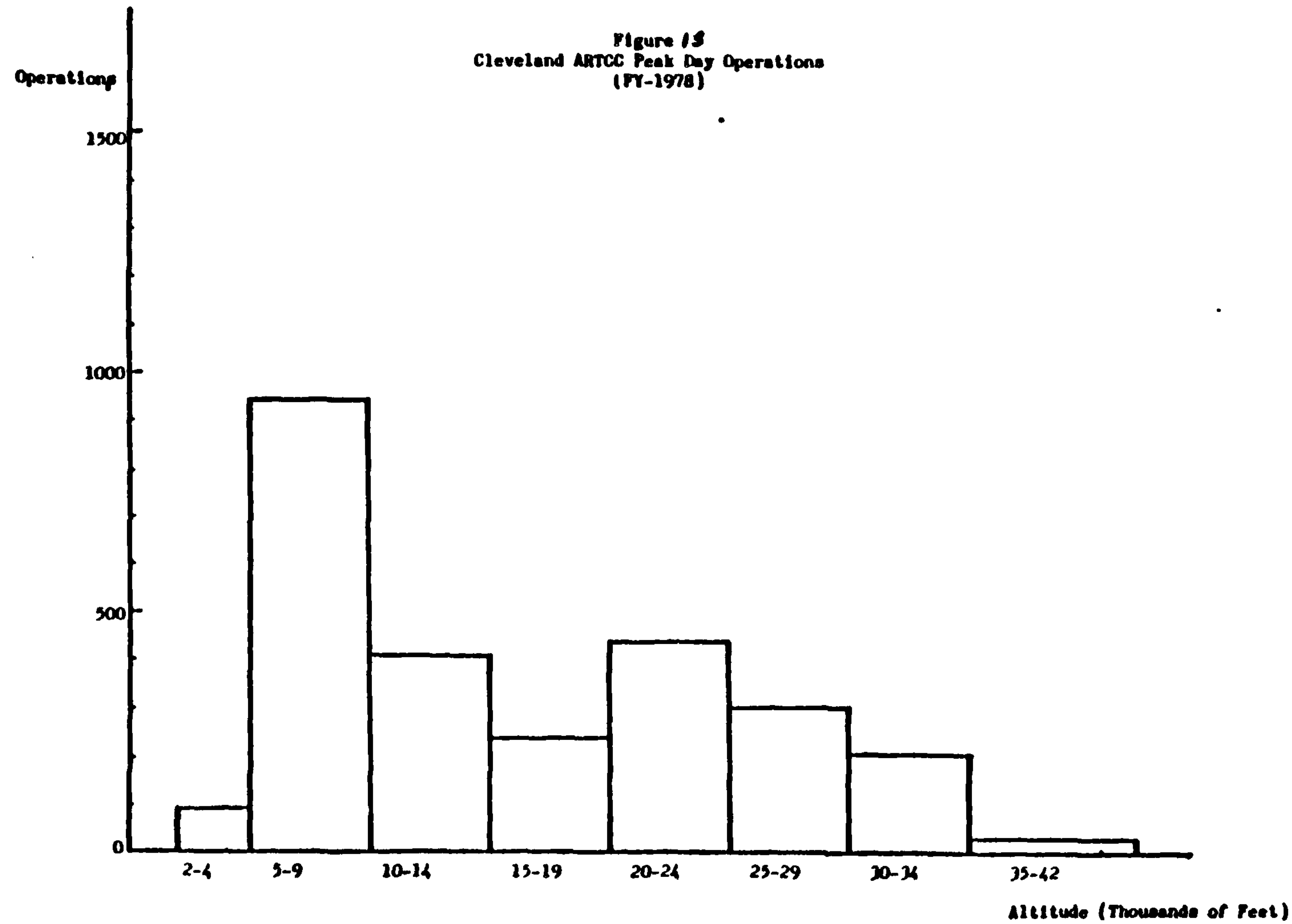
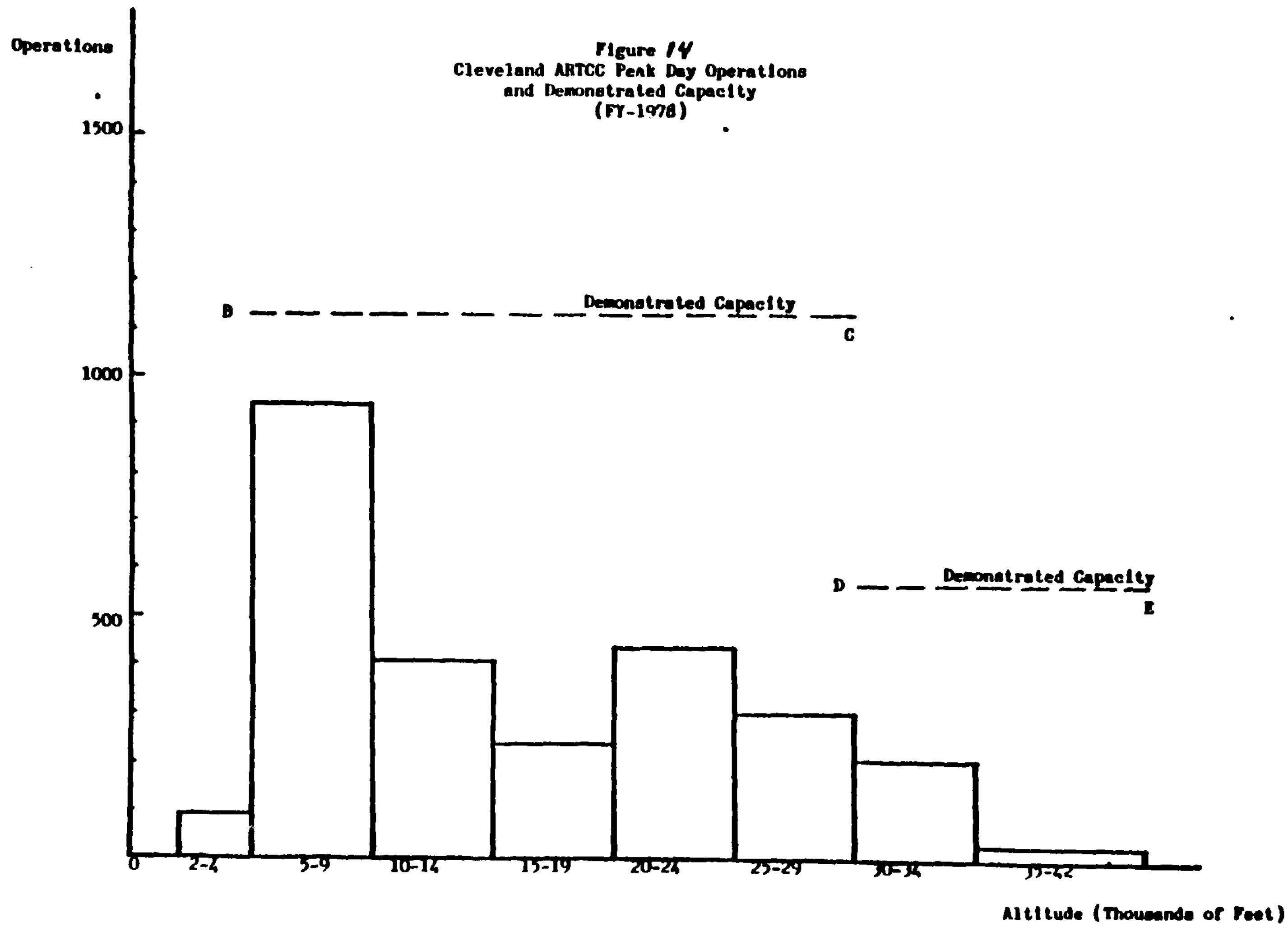


Figure 14
Cleveland ARTCC Peak Day Operations
and Demonstrated Capacity
(FY-1978)



The preceding analysis is limited to the availability of airspace to accommodate given traffic densities under existing control technology. The existence of underutilized airspace, however, is a necessary, but not a sufficient condition to assume adequate en route capacity. Adequate FAA staff, facilities, and equipment (surveillance, data processing, and communications) must be available to control traffic. Under normal, non-strike conditions, FAA controller staffing is determined as a function of air traffic levels (Air Traffic Staffing Standards, March 10, 1980, FAA Order 1380.33B) and can be adjusted within a relatively short period of time, assuming sufficient budget authority. Facilities and equipment, because of the long procurement and installation time, can be an effective constraint. Much concern has been expressed recently about the adequacy of computers used for en route control.

The central computer at each ARTCC consists of an IBM 9020 system of either the "model A" or "model D" type. The significant difference between the two is that the 9020D, installed at the busier centers, has about 2.5 times faster processing than the 9020A. The computers perform basic air traffic surveillance functions such as flight plan processing and radar track generation. They also provide such ancillary functions as conflict alert, minimum safe altitude warning, controller simulator training, and system recording. The capacity of both models to provide these services is finite. Since additional capacity will not be available until replacement equipment is installed in the late 1980's and early 1990's, the capacity of the system is bounded over the next decade by the 9020 capacity. The significance of this bound is indicated in Table 17.

TABLE 17

ARTCC Computer Utilization

Center	9020 Model	Mean Peak Utilization	Projected 1992 Mean Peak Utilization
Albuquerque	A	78%	117%
Atlanta	D	37	55
Boston	A	63	88
Chicago	D	N/A	N/A
Cleveland	D	51	74
Denver	A	N/A	N/A
Fort Worth	D	N/A	N/A
Houston	A	84	128
Indianapolis	D	40	58
Jacksonville	D	31	46
Kansas City	D	34	44
Los Angeles	D	39	56
Memphis	A	73	109
Miami	A	69	102
Minneapolis	A	71	98
New York	D	59	85
Oakland	A	N/A	N/A
Salt Lake City	A	60	104
Seattle	A	N/A	N/A
Washington	D	39	56

Based on Jacques Press, Computer Utilization at Several En Route Air Traffic Control Centers (A3D2.9 System), ARD-140-1-81, December 1980.

Table 17 reports current and projected computer utilization estimates based on data and analysis contained in a recent FAA study (Jacques Press, Computer Utilization at Several En Route Air Traffic Control Centers (A3D2.9 System), ARD-140-1-81, December 1980). As can be seen, the 9020D installations are currently experiencing mean peak utilization of about 60 percent or less. Mean peak utilization for the smaller 9020A installations is somewhat higher. At two 9020A sites—Albuquerque and Houston—utilization is about 80 percent. Projections to 1992 indicate that computer capacity at 9020D locations should not become a problem before replacement equipment is available. At 9020A locations, capacity will be approached at several centers and is projected to be substantially exceeded at Albuquerque and Houston.

Continued operation of the ATC system at locations where computer capacity is approached could require that access to the system be limited at peak times. This is an unlikely outcome, however. It may be possible to increase the capability of the current system by making the existing software more efficient. Analysis has indicated that additional processing capability is available in the input/output processing but is not being utilized due to software design.

In addition, it must be recognized that computer loading to a large extent depends upon what functions and interfaces the Air Traffic Service elects to automate. If computer utilization approaches capacity, they have the clear choice of limiting access to the airspace or reducing the ancillary functions performed by the system. The curtailing of automated functions will have the effect of increasing controller workload. The increase in controller workload would be mitigated, however, by the fact that those locations projected to have capacity utilization problems are responsible for the least intensively used airspace.

A recent FAA report (Operational Delay Day Forecasts for the Twenty Air Route Traffic Control Centers for the Years 1982 through 2011, Final Report, June 1981) concludes that procedural changes or delay impositions may become necessary at five 9020-A sites within the next few years, three more 9020-A sites during the mid-1980's, and the final two 9020-A sites in the late 1980's. The 9020-D sites are concluded to be sufficient until well into the 1990's or beyond.

Entry and exit from the en route system constitutes another potential capacity problem. Comparisons of IFR traffic at hubs with Type I Terminal Control Areas (TCA) with total IFR traffic handled by the centers which contain the hubs indicate the extent to which traffic is concentrated around the hub. (Hubs with Type I TCA's were chosen for examination since they were established because of an existing congestion problem.)

Table 18 presents IFR traffic data for selected centers and hubs. Of the nine hubs examined, six had ratios of hub instrument traffic-to-center instrument traffic of 58 percent or less. Of significance are the other three where IFR traffic operating into or out of the hub airports accounted for 68 percent or more of total center IFR traffic. Los Angeles center had 93 percent of its traffic arriving or departing Los

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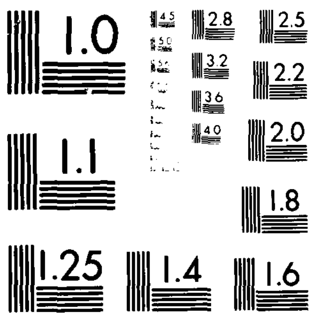


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

TABLE 18

IFR OPERATIONS AT LARGE HUBS WITH
TYPE I TCA's RELATIVE TO ARTCC IFR OPERATIONS IN 1979
(Thousands of Operations)

Location	IFR Operations		Hub as Percent of Center
	Hub Airports	Center	
Atlanta	865	1,703	50.8%
Boston	528	1,099	25.3
Chicago	1,032	2,084	49.5
Fort Worth	902	1,644	54.9
Los Angeles	1,349	1,449	93.1
Miami	1,124	1,482	75.8
New York	1,034	1,771	58.4
San Francisco	588	1,233	47.7
Washington	1,110	1,621	68.5

Angeles hub airports, Miami center 76 percent of its traffic arriving or departing Miami hub airports, and Washington center 68 percent of the traffic arriving or departing Washington hub airports. The high percentages of IFR traffic being funneled into and out of the hubs in these three centers suggests that if congestion exists at the terminal/center interface, it exists at these three locations.

There is evidence that congestion at the terminal/center interface may be already happening in Southern California. Over the first nine months of 1980, Los Angeles center experienced the greatest number of system errors of any center. This occurred despite several other centers having handled more traffic than Los Angeles and most other centers having greater traffic density. (See Table 16.) Moreover, Southern California accounted for 24 percent of all midair collisions in areas of radar coverage between 1969 and 1978. Since such collisions are more than proportionally related to traffic, their relatively high incidence in Soutern California may be indicative of airspace congestion in this area.

3. The Future

As indicated in Table 1, IFR aircraft handled at centers is projected to grow 40 percent between 1980 and 1990. The largest component of center traffic growth is expected to be general aviation, followed by commuter airlines. General aviation as a proportion of total center traffic is expected to increase from 30 percent in 1980 to 37 percent in 1990.

Projected 1992 en route operations per square mile, Table 16, reveal that five centers will experience traffic density higher than the highest level experienced in 1980.

With respect to the future capability of the en route ATC system to accommodate additional traffic, data are more limited than what are available on the current state of the system. An indication of the adequacy of current technology to perform en route air traffic control in the future may be obtained by projecting future center traffic by altitude under two alternative traffic growth scenarios:
(1) proportional traffic growth at all altitudes ("Proportional Growth"), and (2) differential rates of traffic growth by altitude ("Large Low Altitude GA Growth").

Under "Proportional Growth," 1992 traffic at each altitude is projected at the average growth rate of all en route IFR traffic (see Table 19). These projections indicate that at 14 of 20 centers, total traffic would exceed previously demonstrated capability between 5,000 and 10,000 feet. In Figure 15, this traffic is represented by the area [illegible]. At three of these fifteen, however, projections exceed previously demonstrated capability by only small amounts. Thus, potential capacity shortages between 5,000 and 10,000 feet can be ruled out under the "Proportional Growth" scenario at about one-third of the centers. At the other centers, physical congestion at these altitudes may or may not be a potential problem, depending on (1) whether or not previously demonstrated capability was the maximum capability, and (2) the ability

Figure 15
Cleveland ARTCC Projected Peak Day Operations
and Demonstrated Capacity
(FY-1992)

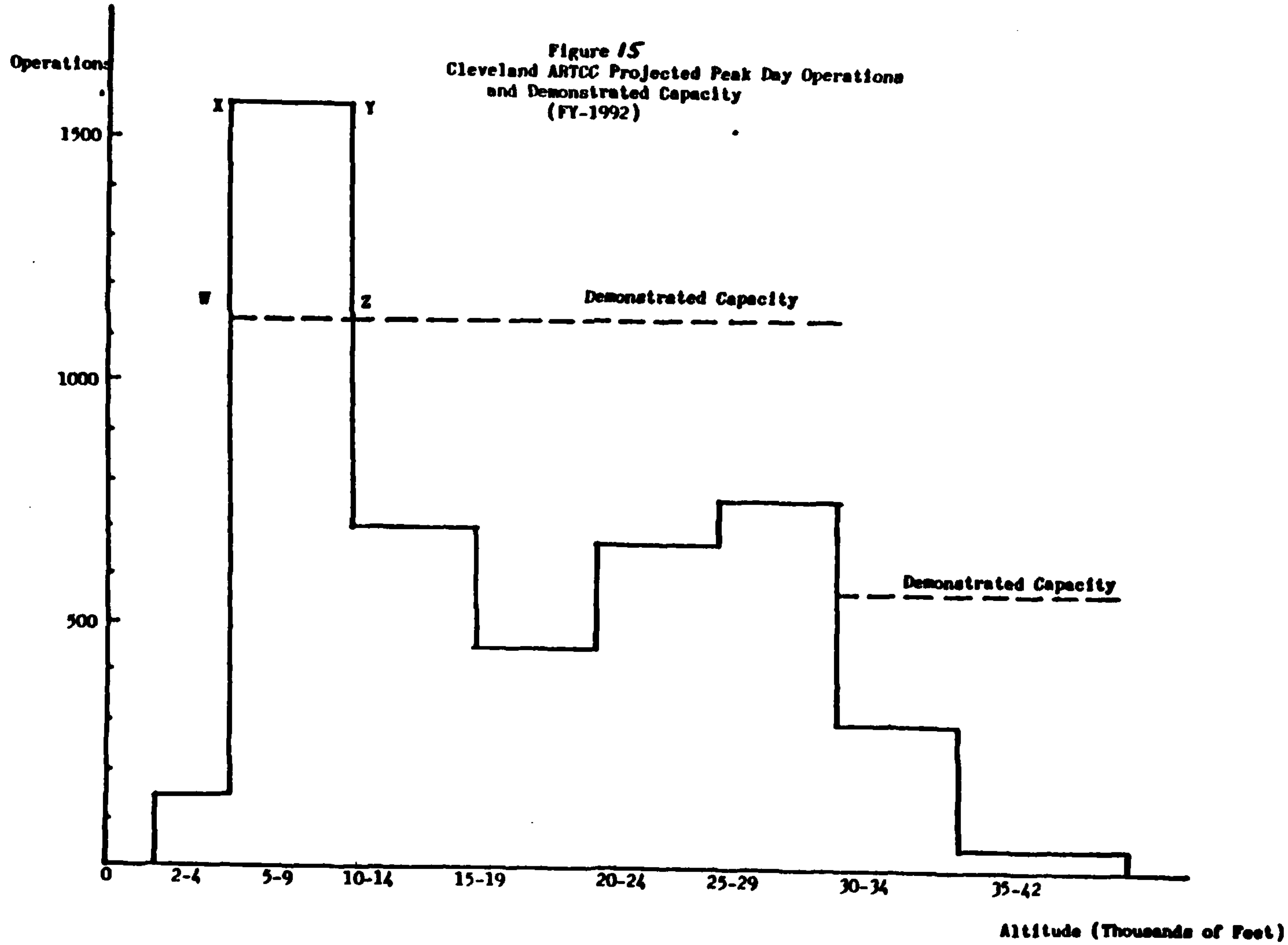


TABLE 19

PROJECTED 1992 ARTCC PEAK DAY TRAFFIC AT SELECTED ALTITUDES

Center	5,000-9,000 Feet			10,000-14,000 Feet		
	Demon-strated Capacity	Propor-tional Growth	Large GA Growth	Demon-strated Capacity	Propor-tional Growth	Large GA Growth
Albuquerque	320	471	559	555	529	737
Atlanta	865	1,147	1,766	865	524	403
Boston	1,545	1,293	1,414	1,545	330	367
Chicago	1,780	2,080	2,267	1,780	621	684
Cleveland	1,125	1,468	1,570	1,125	631	681
Denver	310	215	236	310	321	350
Forth Worth	1,030	1,278	1,383	1,030	440	462
Houston	1,090	1,252	1,291	1,090	531	573
Indianapolis	965	1,171	1,211	965	504	526
Jacksonville	860	885	891	860	282	299
Kansas City	835	1,254	1,306	835	365	405
Los Angeles	725	669	704	935	570	946
Memphis	895	1,096	1,128	895	424	457
Miami	1,205	1,162	1,138	1,205	338	389
Minneapolis	1,290	1,447	1,498	1,290	406	472
New York	1,010	864	919	1,010	274	310
Oakland	695	700	709	695	332	352
Salt Lake City	230	191	202	245	318	320
Seattle	695	775	831	695	527	568
Washington	730	817	790	730	392	442

to shift traffic from the desired to adjacent altitudes. Projected 1992 traffic for other altitudes does not reach previously demonstrated capabilities, except at two centers. At Salt Lake City and Denver, projected traffic exceeds demonstrated capacity by a small amount. Sufficient additional capacity exists at lower and higher altitudes to absorb the excess.

Under the second scenario, Large Low Altitude GA Growth, traffic growth is projected for each altitude for each generic aircraft type, using official FAA aircraft forecasts. This procedure recognizes that changing demands for and costs of air transportation will be reflected in activity patterns of different aircraft types. Each aircraft type has a unique optimum flight profile, and changes in relative operations by aircraft type will affect demand for ATC service at each altitude differently.

Under this scenario, traffic growth is larger at the lower altitudes because the faster growing general aviation component is concentrated here. The outcome with respect to potential congestion is similar to that under the Proportional Growth scenario. At altitudes below 10,000 feet, fourteen centers will experience traffic activity in excess of demonstrated capacity. At altitudes between 10,000 and 14,000 feet, previously demonstrated capacity is reached at four centers, as opposed to two under Proportional Growth. Only at Albuquerque will excess traffic possibly need to be shifted higher to accommodate peak demand, but the low traffic density of Albuquerque (See Table 16) suggests that demonstrated capacity is actually well below true capacity.

In addition to the higher density of en route traffic, it seems likely that there will be increasing congestion at the interface between terminal and en route airspace. Los Angeles, Miami, and Washington centers will experience this problem as may other centers experiencing substantial growth in terminal operations.

C. Conclusions

Airfield delay is a function of traffic density, which reflects the continously changing relationship between demand and capacity; capacity is especially dependent on weather conditions. As the level of delay at any airport increases, a variety of reactions is possible, including mere acceptance of higher levels of delay. Because the use of any airport is voluntary, existing delays at major airports are considered tolerable. They are not desirable, however, because they may *impose additional* transportation costs. The tolerable level differs among major airports because of differing airport roles in the national air transportation network.

Based on SDRS data, the nationwide average delay per operation due to all causes was 5.9 minutes in 1980, yielding a systemwide delay cost to air carriers of $1.4 billion per year. These must be considered upper bound estimates. The data and an analysis of the data reveal that SDRS may report a minimum delay of nearly three minutes per operation at any airport. Reasons for this may include: the reporting of some en route delay not attributable to airports; the fact that some queuing delay is unavoidable for both arrivals and departures; the use of one standard taxi time per airport based on the average time for all runways; and the fact that severe weather causes unavoidable delays at every airport. Because of these factors, the cost of delay which may be subject to elimination is closer to $0.9 billion. An unknown amount of this cost is consciously borne by airlines who accept higher than necessary delays in exchange for more desirable schedules. Over the period 1976 through 1980, most delays (50 percent) were of short duration, 5 minutes or less, with only one percent or less of operations experiencing delays exceeding 30 minutes. Long delays were almost exclusively attributable to weather.

Between 1980 and 1991, operations at the 39 largest United States airports may grow by 31 percent, even though many airports may be subject to operations constraints. Assuming no change in the existing airfield capacity of these sites, average delay per operation may grow by as much as 47 percent. The combined effect of increased operations and increased average delay could be to increase systemwide air carrier delays up to 93 percent. Valuing these delays at 1980 unit costs, delays could add $1.3 billion a year to the cost of air carrier travel by 1991.

For 20 of the 39 airports considered, average delay per operation may remain tolerable (8 minutes or less) without any change in the pattern of use. For the remaining 19 airports, changes may be required. Seven major airports would benefit from a redistribution of general aviation traffic and four major airports might obtain relief from a redistribution of air carrier traffic to nearby air carrier airports. Eight major airports (representing seven cities) could face severe congestion which cannot be sufficiently mitigated by either reduced general aviation use or redistribution of air carrier traffic to nearby available airports. Uncertainties in forecasting airport operations could alter these conclusions. However, the probability of overestimating airport operations appears low; the potential cost of a degraded air transportation system resulting from inadequate capacity is high.

The limited circumstantial evidence available on en route capacity and en route caused delay suggests that capacity is generally adequate and that delay, if it exists at all, is small. Traffic densities vary substantially among centers. Some centers such as Cleveland, Chicago, Indianapolis, Atlanta, and Washington may experience high enough traffic volumes to result in the assignment of suboptimal routings. Traffic densities also vary substantially by altitude within a center. This suggests that a substantial amount of en route airspace is relatively underutilized, although it is uncertain whether FAA facilities and equipment are sufficient to make intensive use of this space.

Computer capacity may impose constraints during the next ten years at as many as 10 en route centers. These may be reflected in procedural changes or delay impositions at those centers with the 9020-A computers. No significant delay problems are anticipated, however.

Entry to and exit from the en route system constitute a potential capacity problem. For Los Angeles, Miami, and Washington centers, operations at hubs with Type I TCA's within the center constitute 70 percent or more of center operations. Relatively high numbers of ATC system errors and midair collisions (in areas of radar coverage) provide circumstantial evidence of congestion in the Los Angeles center area.

Projected 1992 en route operations per square mile at five centers will exceed the highest density experienced in 1979. By 1992, assuming proportional growth by altitudes, 15 of 20 centers will experience traffic volumes at altitudes between 5,000 and 10,000 feet which exceed previously demonstrated capacity. If large low altitude GA growth is assumed, projected traffic below 15,000 feet would exceed demonstrated capacity at fourteen centers and high altitude traffic would exceed demonstrated capacity at four centers. Physical congestion at these altitudes may be a problem if (1) previously demonstrated capacity is the maximum capacity, and (2) traffic cannot be shifted from the desired to adjacent altitudes. It also seems likely that there will be increasing congestion at the interfaces between TCA and en route airspace.

IV. OPTIONS TO ACCOMMODATE FUTURE ACTIVITY

Discussed in this Chapter are potential actions for accommodating future aviation activity. For airfield activity, the options are categorized as airport development, air traffic procedures, nontechnical actions, and other actions. Discussion of en route options focuses on air traffic procedures and nontechnical options.

In considering these options, it is important to note that there exist subjective capacity constraints or limitations on both airspace use and airport use. These constraints are the product of the attitudes and feelings of individuals and communities and represent basic value judgments. Often, these value judgments are antagonistic toward aviation. Illustrations of subjective capacity constraints include the new Washington National Airport Policy, the Orange County limit on the daily number of air carrier flights at the John Wayne Airport, and the overall noise limit established at the Hollywood-Burbank Airport. Illustrations of the antagonistic attitudes and value judgments are myriad—litigation to prevent installation of a long range radar in Massachusetts and Virginia as well as an ILS at Westchester, New York and Fort Lauderdale, Florida; opposition to authorizing jet aircraft at Jackson Hole, Wyoming; and extensive litigation concerning airport development projects of every description from Atlanta's new terminal to Detroit's new runway to the Caldwell, Idaho Airport and the Concord, New Hampshire Airport/industrial park complex.

Subjective capacity constraints on airspace use and airport use are real. They not only exist and, therefore, must be considered, but since they are the product of a basic value judgment, they are issues which are not resolvable by the FAA and which are usually antagonistic toward any proposal to increase airspace/airport capacity.

A. Airfield Options

Lack of adequate capacity is expected to be a severe problem in accommodating air carrier traffic for at least eight airports by 1990, and eleven other airports will require some alleviation of airport use in order to accommodate air carrier activity (see Chapter III.A.7). Potential actions to alleviate congestion problems at the major hub airports and facilitate better use of alternative facilities are discussed below.

1. Airport Development

Other than Washington National and Dulles International Airports, the airports of the United States were created and are owned, operated, managed and maintained by a variety of local governmental entities to serve perceived local needs. The FAA's authority in the area of airport development has been limited to the ability to make grants to airport sponsors under the Airport and Airway Development Act of 1970, as amended by 49 U.S.C. 1701 et. seq. (authority to issue development grants under the Act lapsed September 30, 1980). This authority has been subject to two major constraints, one financial and one procedural.

First, there has been a dollar limit on obligational authority. By statute, one-third of all airport development money has been distributed per a state apportionment formula based on a state's population and size. (Section 15(a)(1)(A), 49 U.S.C. 1715(a)(1)(A)). Another third has been distributed to sponsors of airports served by certificated air carriers based on a passenger enplanement formula. (Section 15(a)(1)(B), 49 U.S.C. 1715(a)(1)(B)). Distribution of the final third has been pursuant to the discretion of FAA. (Section 15(a)(1)(C), 49 U.S.C. 1715(a)(1)(C)).

The second major limit on the FAA's ability to direct airport development to specific projects has been that no grant could be issued without a request from an airport sponsor, and that an airport sponsor was free to request grant-in-aid funds for any eligible development project. (See Section 11(3), 49 U.S.C. 1711(3) for the definition of airport development, and see 14 CFR 152.45). While the FAA could establish project priorities, it could not force those priorities on an airport sponsor. In short, it has been the local airport sponsor, not the FAA, who made the critical decisions regarding airport development. The sponsor has decided whether or not any development would occur. The sponsor has also decided the specific development project to be pursued.

Assuming that at a specific airport there were identifiable development projects which, if undertaken, would increase the airport's capacity, there have been no requirements or obligations on the airport sponsor to pursue such projects. The airport sponsor has been free to reject those projects which would increase airport capacity and apply for grant-in-aid funds available to it via the various statutory formulas to pursue noncapacity related projects—e.g., retire airport terminal development bonds or acquire land for noise abatement purposes rather than construct a runway extension or add aircraft parking facilities.

Given the statutory authority of the FAA with respect to airport development, the fundamental approach of the FAA to capacity and delay problems has been to increase the efficiency of use of existing major hub airports. To achieve this objective, the FAA traditionally has assumed a responsive and advisory role rather than directly initiating and implementing airport development. For example, task forces have been created to promote the identification of capacity/delay problems and encourage communication among affected parties. The principal impetus for airport development has come from airport sponsors, a result of the legal framework established for FAA participation in airport development.

Ongoing FAA aiport development activities related to the capacity/delay problem are the National Airport System Plan (NASP), Airport Development Aid Program (ADAP, for which authority lapsed September 30, 1980), Metropolitan Area Assessment, satellite/reliever airports, primary hub concept, and joint aviation/military use airports. The NASP identifies airport development projects in which there is a potential Federal interest and on which Federal funds may be spent. It reflects airport development needs primarily as perceived from a local perspective. NASP is not a system plan in the traditional sense, but sets forth what individual airports want. ADAP provides grants for planning and development to qualified airports. Between 1971 and 1980, ADAP grants totaled $3.3 billion. About 42 percent of these grants were for capacity related projects, but only 17 percent of total ADAP grants were for capacity projects at large hub airports. The Metropolitan Area Assessment is a newly initiated program, which examines an airport's most urgent development needs and estimate the cost and timing of potential solutions. The satellite airport program is designed to accelerate the development of secondary metropolitan airports. Its objective is to reduce the volume and mix of aircraft at major air carrier airports by making satellite fields more attractive to private and business flyers. The FAA has proposed that legislation establish a separate funding category to provide funds to major hubs for airport system planning and development. The objective is to provide a mechanism for local airport operators to work together in planning the development of their areas' airports. The FAA is an active proponent of joint military-civilian use airports and has identified 42 locations where joint use would be desirable if the military would permit it.

At present, the FAA anticipates that new, major airports will be limited to locations where planning has already begun. A new airport at Palmdale, California, to serve the Los Angeles Basin may be the only airport to open in the decade ahead. Land acquisition and initial construction for a second Atlanta airport may also take place during that time, and a timetable and decision regarding a possible new San Diego airport may be established. Development costs for both large and small new airports represent only 13 percent of presently planned NASP development.

Given the assessment of likely future airfield capacity/delay problems, three broad airport development options appear relevant:

- Expansion or construction of major airports;
- Construction of independent short runways for commuter and general aviation use at airports where existing capacity is probably inadequate to accommodate projected demand through 1990.
- Increased development of satellite/reliever airports.

These are each discussed below.

a. Expansion or Construction of Major Airports

Every airport serves as an origin/destination airport for local residents. A small group of airports also serves as important sites for domestic connections and international traffic. Based on traffic estimates for the 21 largest airports (as listed in Table 10), the top ten airports in proportion of connecting traffic and proportion of international traffic are listed in Table 20.

TABLE 20

LEADING CONNECTION AND INTERNATIONAL AIRPORTS
AMONG 21 LARGEST AIRPORTS

Airport	% of Enplanements Which are Connecting	Airport	% of Enplanements Which are International
ATL	76.3%	JFK	49.0%
DFW	51.8	MIA	28.0
DEN	51.6	BOS	16.1
ORD	50.4	HNL	12.9
STL	48.7	LAX	9.0
PIT	46.2	SEA	7.5
MSP	33.3	PHL	6.8
SEA	32.1	SFO	5.5
MIA	30.5	EWR	5.1
JFK	30.0	IAH	5.0

Note that each city identified in Table 14 as requiring additional capacity is represented in Table 20. The major airports in these cities are the key elements in the national air transportation system; they provide benefits to the national system as well as serving local residents or visitors as a point of origin or destination. Communities where national airports are located, however, may not be motivated to sponsor expansion associated primarily with national system requirements. Moreover, local communities may be unwilling to endure adverse environmental impacts associated with the system component of traffic and may not be financially able to mitigate the impacts.

Even if a local community is willing to expand its airport facilities, there may be substantial impediments. Probably the most important difficulty is uncertainty about the physical ability to expand existing sites or to find new sites. This difficulty is not considered insurmountable, however, given previous planning and discussion involving

TABLE 21

EXAMPLES OF AIRPORT DEVELOPMENT COSTS

Airport	Facility	Date	Cost
Seattle (SEA)	Terminal	1971	$183 million
Kansas City (MCI)	New Airport	1972	$215 million
Dallas-Fort Worth (DFW)	New Airport	1974	$875 million
Atlanta (ATL)	Terminal	1980	$485 million
	Runway	Proposed	$70-80 million
	Land	Proposed	$15 million

new runways or airports at Los Angeles, St. Louis, Atlanta, Denver, and elsewhere. Even if airport expansion is physically possible, the cost of improving existing sites or building new ones would probably require billions of dollars, perhaps tens of billions. Table 21 provides cost data on recently constructed airports and airport additions.

b. Short Runway Construction

The FAA's Office of Systems Engineering Management (OSEM) has been evaluating the concept of congestion relief through the construction of independent short runways for commuter and GA use at the top thirty airports (in terms of 1976 air carrier operations). Each of the thirty airports was surveyed to determine the feasibility of constructing (or extending) an independent 4,000 foot runway dedicated to operators of small aircraft. Congestion relief is achieved by providing additional runway capacity and by increasing the capacity of existing runways as a result of reduced separation standards attainable with a more homogeneous mix of aircraft. Eleven airports have been identified where the construction of short runways is considered possible (see Potential Benefits of the Use of Separate Short Runways at Major Airports, [5]). Eight of the feasible sites are airports where present capacity is considered inadequate to accommodate projected 1990 traffic--JFK, STL, PHL, DEN, ATL, ORD, DFW, IND. The OSEM sponsored studies [5 and 20] suggest that substantial delay savings, under IFR conditions, can be obtained due to an increase in capacity through the use of separate short runways. The short runway initiative is not considered feasible at the ten other sites idenified in Chapter III.A.7. as being expected to have future congestion problems. [1] Also, even where such runways are physically feasible, they may not remedy airport congestion solely associated with a large number of air carrier operations such as at ATL.

c. Satellite/Reliever Airports

In recent years, the FAA has initiated a satellite airport program designed to accelerate the development of secondary metropolitan airports—relievers as well as other close in locations. The objective is to reduce the volume and mix of commercial aircraft at major air carrier airports by making neighboring satellite fields more attractive to private and business fliers. Both ADAP grants and FAA facility and equipment purchases are used to upgrade satellite facilities.

To date, the satellite airport program has been a quick response by the FAA to provide congestion relief. It is the FAA's desire to use the program for long run development of the total general aviation and reliever airport system in metropolitan areas under an extended Airport and Airway Development Act. A total of 86 satellite fields are proposed for short term improvement projects over the next three years.

The most significant benefits from existing and planned satellite airport program projects will be realized in those areas containing the nineteen terminals identified in Chapter III.A.7. as potentially lacking adequate capacity to accommodate projected 1990 traffic. The cost of projects

1/ IAH, LAS, MEM, PHX, SAN, SFO, DCA, BOS, LAX, LGA.

associated with the nineteen airports for FY-1979 through FY-1982 was $42.3 million, or 46 percent of planned program expenditures. This suggests that the satellite airport program, while it provides relief to major airports in 56 metropolitan areas, is giving greater emphasis to airports likely to experience extreme congestion during the coming decades.

Major advantages of the satellite/reliever airports program are its positive approach to shifting general aviation operations away from busy air carrier airports and its compatibility with the historical ADAP funding formula and FAA role. The program by itself, however, cannot solve all congestion problems. As noted in the discussion of independent short runways, some airports may experience severe congestion solely as a result of the large number of projected air carrier operations. Also, the satellite/reliever program is dependent on the initiative of local airport sponsors to apply for ADAP grants and on the availability of suitable satellite/reliever airport sites.

2. Air Traffic Procedures

The general priorities of air traffic controllers as prescribed in the ATC manual are:

- The separation of aircraft; and
- The provision for service on a "first-come-first-served" basis.

To accomplish these objectives, rules have been promulgated regarding aircraft departures and arrivals. See Chapter II.C.1. for a description of these rules.

The following five approaches to increasing airfield capacity and reducing delay involve potential changes in air traffic procedures, sometimes in conjunction with the development of new facilities and equipment:

- Reduced runway occupancy time;
- Reduced separation standards achieved by wake vortex elimination or detection;
- Reduced separation standards achieved by the use of dual glide slopes;
- Traffic management to increase capacity and mitigate the adverse impacts of delay; and
- Changes in the use of parallel and converging runways.

These options are discussed separately below.

a. Runway Occupancy

The ability to increase runway capacity by reducing minimum aircraft separation standards may be constrained by the time it takes the preceding aircraft to exit a runway. The runway occupancy rule prohibits a following aircraft from crossing a runway threshold while the preceding aircraft occupies the runway. The usual ATC procedure is to institute a go-around for the following aircraft if that aircraft has not exited the runway. Therefore, under current practices, an effort to decrease minimum separation standards may increase the go-around rate unless average runway occupancy times can be decreased or the runway occupancy rule is changed. The implication of an increased go-around rate would be to increase delays for some aircraft, thereby increasing fuel use.

The ability to reduce runway occupancy time is constrained by several factors, including:

- Meteorological conditions. Wet runways or poor visibility increase runway occupancy times;
- Aircraft types. Various aircraft have differing abilities to decelerate and maintain stability;
- Available exits. At certain airports, exits are located such that aircraft must taxi greater distances and remain on the runway for relatively longer periods; and
- Pilot motivation. In some instances, pilots will not decelerate quickly, so as to maintain passenger comfort; in other instances, pilots will exit the runway nearest their terminal.

Table 22 describes recorded runway occupancy time data at major airports. Note that mean runway occupancy times vary by aircraft type for the same runway and by airport for identical aircraft. The average runway occupancy times to attain minimum separation standards of 3.0, 2.5 and 2.0 n.mi. with the current ATC system are 63, 50, and 39 seconds, respectively. 1/

1/ Assumes a normal distribution with a 6 percent go-around rate from a 140 n.mi./hr. arrival speed.

TABLE 22

RUNWAY OCCUPANCY TIME DATA

Aircraft	Runway	Mean Runway Occupancy (secs.)	Standard Deviation (secs.)
BAC 111	ATL 27R (26)	51.4	7.5
DC-9	BUF 5	50.7	13.8
B727	BUF 23	55.9	8.7
	DEN 26R	51.5	8.4
	LAX 25L	48.2	10.4
	LAX 22R	52.6	14.1
	LGA 22	43.3	9.5
	LGA 31	40.7	8.5
	SFO 28R	47.4	9.2
	SFO 28L	49.3	8.1
B707	DEN 26R	55.1	9.4
DC-8	LAX 25L	50.9	9.6
L1011	LAX 25R	60.2	16.8
DC-10	SFO 28R	57.2	16.5
B747	SFO 28L	55.0	13.4

Source: "Analysis of Runway Occupancy Times at Major Airports," FAA-EM-78-9, May 1978.

Options to decrease runway occupancy times include:

- o Installing high speed exits and improving the taxiway network. This practice may impact passenger comfort and must be combined with airline company policy stressing pilots taking the nearest exit;

- o Changing the runway occupancy rule. The rule may be altered such that when an aircraft has passed a certain point down a runway, the following aircraft at the go-around threshold will be allowed to land. This procedure will require increased dependence on air traffic controller judgement; and

- o Improving the ATC system. The MLS may allow for reduced separation standards and longer average runway occupancy time than the current ATC system.

b. Wake Vortex Elimination or Detection

Over the past ten years, two different approaches have been undertaken by the Federal Government. NASA concentrated on the mechanics and causes of vortices and methods to alleviate them at the source. These efforts have not reached a stage where either the airframe manufacturers or aircraft operators feel that wake vortex alleviation systems are achievable. FAA has concentrated on developing wake vortex detection and avoidance systems and has been moderately successful in characterizing wake and developing meteorological means for predicting the probable location of wake vortices. A system was tested at O'Hare and proven technically sound. It has not been found operationally acceptable by the users.

b. Dual Glide Slopes

Another potential approach to the wake vortices and aircraft separation standards is the use of multiple glide slopes for the same runway. It has been proposed to use the microwave landing system (MLS) in a multiple glide slope application where light aircraft operate on a 4° glide slope and large aircraft can operate on a 3° glide slope, providing 500 to 1,000 feet of separation between the two paths. Successful implementation of such a procedure requires solution to several operational problems including the vortex hazard of a missed approach from the lower glide path and the difficulty of requiring the lighter aircraft to land as much as 2,000 feet down the runway past the touchdown point for the large aircraft. In addition to these technical problems, there may be a great deal of pilot resistance to implementation of the procedure. One estimate of potential capacity gains is up to 11 percent depending upon the mix of heavy aircraft and the extent of MLS equipment in light aircraft.

c. Traffic Management to Increase Capacity and Mitigate Delay

Traffic management can be characterized as an ATC process of efficiently utilizing available airfield facilities (runway configuration, gate control, etc.) and approach control equipment (radar communications, landing aids, etc.) to increase terminal area capacity and reduce delay given local constraints (noise abatement, construction, etc.),the maintenance of ATC rules and regulations, and the integrity of air carrier schedules.

Potential traffic management techniques include:

i) Sequencing aircraft to land and takeoff according to their performance characteristics (single runway operations);

ii) Segregating air traffic for arrival/departure runways by performance characteristics (multiple runway operations); and

iii) Implementing flow control techniques away from the terminal area to affect the arrival/departure rates of aircraft entering/leaving the terminal area to reduce airborne delay.

As discussed above, runway throughput capacity (a theoretical maximum) is constrained by practical limits predicated upon interarrival randomness and runway occupancy. Though it may be possible to reduce the separation standards of aircraft in flight, the runway occupancy rule may limit the potential benefits of air traffic procedural changes for increasing airport capacity and reducing aircraft delays.

i. Class Sequencing

Due to the different performance characteristics of aircraft, such as approach and departure speeds and wake turbulence determined by aircraft size, various separation standards must be maintained to assure safety. Class sequencing is an ATC procedure to order aircraft landings and takeoffs in accordance with their performance characteristics. It primarily relates to single runway operations, and it alters the first-come-first-served principle in an effort to maximize capacity in the terminal area.

An 1972 FAA sponsored study [43] suggests that a speed sequence could be set up such that each aircraft has a speed at least equal to that of the preceding aircraft; whenever a slower aircraft arrives, a new sequence could be started. The analysis concludes that this sequencing procedure leads to large delays for some aircraft and appears to discriminate against slower aircraft. Other combinations of sequencing described in the study are concluded to be unsuccessful. Sequencing is difficult because of the following factors:

- Discrimination against slower aircraft;
- Vast computer requirements to rearrange the arrival sequence whenever a new aircraft enters the arrival sequence;

- Disregard of the first-come-first-served principle; and
- Inability to move aircraft around as the sequence changes, due to limited airspace.

A second study, <u>The Dynamic Scheduling of Aircraft in the Near Terminal Area</u> [44], examines the process of Constrained Position Shifting (CPS). CPS would limit the number of places an aircraft would lose in the landing sequence to four positions.

The study finds that in simulating airport conditions at peak demand (45 operations per hour), CPS resulted in a 43 percent reduction in average aircraft delay and 31 percent reduction in maximum delay when compared with first-come-first served.

Finally, a study performed at O'Hare concluded that weight class sequencing could provide a significant capacity increase only in cases where there was a large percentage of heavy aircraft and a long sequencing interval. The operational implications (higher potential delays to specific aircraft) made weight class sequencing at O'Hare impractical.

ii. <u>Traffic Segregation</u>

Traffic segregation is the grouping of aircraft by performance characteristics and the assignment of homogeneous groups to separate airfield facilities. Traffic segregation is most easily implemented where an airport has multiple runways. In times of peak demand, terminal capacity is constrained by a heterogeneous queue of arriving and departing aircraft requiring extended separations. If, on the other hand, queues can be formed from aircraft with similar performance characteristics to land and takeoff on a designated runway, capacity may be increased by reduced separation standards with no adverse safety impact. Traffic segregation violates the current general ATC priority of first-come-first-served.

One method of traffic segregation pertains to parallel runway operations. It is theoretically possible to increase the capacity of an airfield with a parallel runway configuration by placing lighter aircraft on the runway upwind of the runway used by heavier aircraft. The homogeneity of arrival queues would circumvent the need for increased separations between heavy and light aircraft. Further, if the crosswind could keep the wake vortex of the heavier aircraft from spreading laterally into the paths of the lighter aircraft, it might allow the independent use of closer spaced parallel runways. LAX has used this procedure, although the intent is mainly noise abatement, not increasing capacity.

As described in Section IV.A.1, the FAA is studying the possibility and potential benefits of traffic segregation through the use of separate short runways. Such runways could be installed at a significant number of airports expected to experience substantial congestion problems in the coming decade.

iii. Flow Control

The economics of air travel has imposed another priority on air traffic control: fuel conservation. The Air Traffic Service of the FAA has undertaken several programs designed to conserve aviation fuel. These programs include:

- o Fuel Advisory Departure (FAD); and

- o Expanded Quota Flow (QFLOW) procedures.

Flow control is the balancing of air traffic demand with system capacity to ensure maximum efficiency, thereby producing a safe, orderly and expeditious flow of air traffic while minimizing user delays. The purpose of flow control is to disperse the effects of peak demand periods throughout the air system. This relates to both terminal and en route environments. Conditions suitable for application of flow control are:

- o Periods of specific or expected traffic concentrations in terminal areas which exceed the acceptance rate of the particular airport.

- o Periods of peak traffic en route over specific points or route segments that exceed the ATC system capacity.

- o Periods when meteorological conditions tend to result in an unexpected concentration of air traffic in specific areas or along specific routes.

- o Any other event which may disrupt the normal flow of air traffic.

Operationally, flow control is monitored at the Air Traffic Control System Command Center (ATCSCC) of FAA Headquarters, Washington, D.C. The major function of ATCSCC is to centrally monitor air traffic and issue advisories throughout the ATC field facilities. An advisory is a "notification of actual and/or anticipated air traffic system problems to user and field facilities which will enable them to plan aircraft movements in a safe, orderly and efficient manner." Figure 16 describes the general demand/capacity relationships in the flow control process.

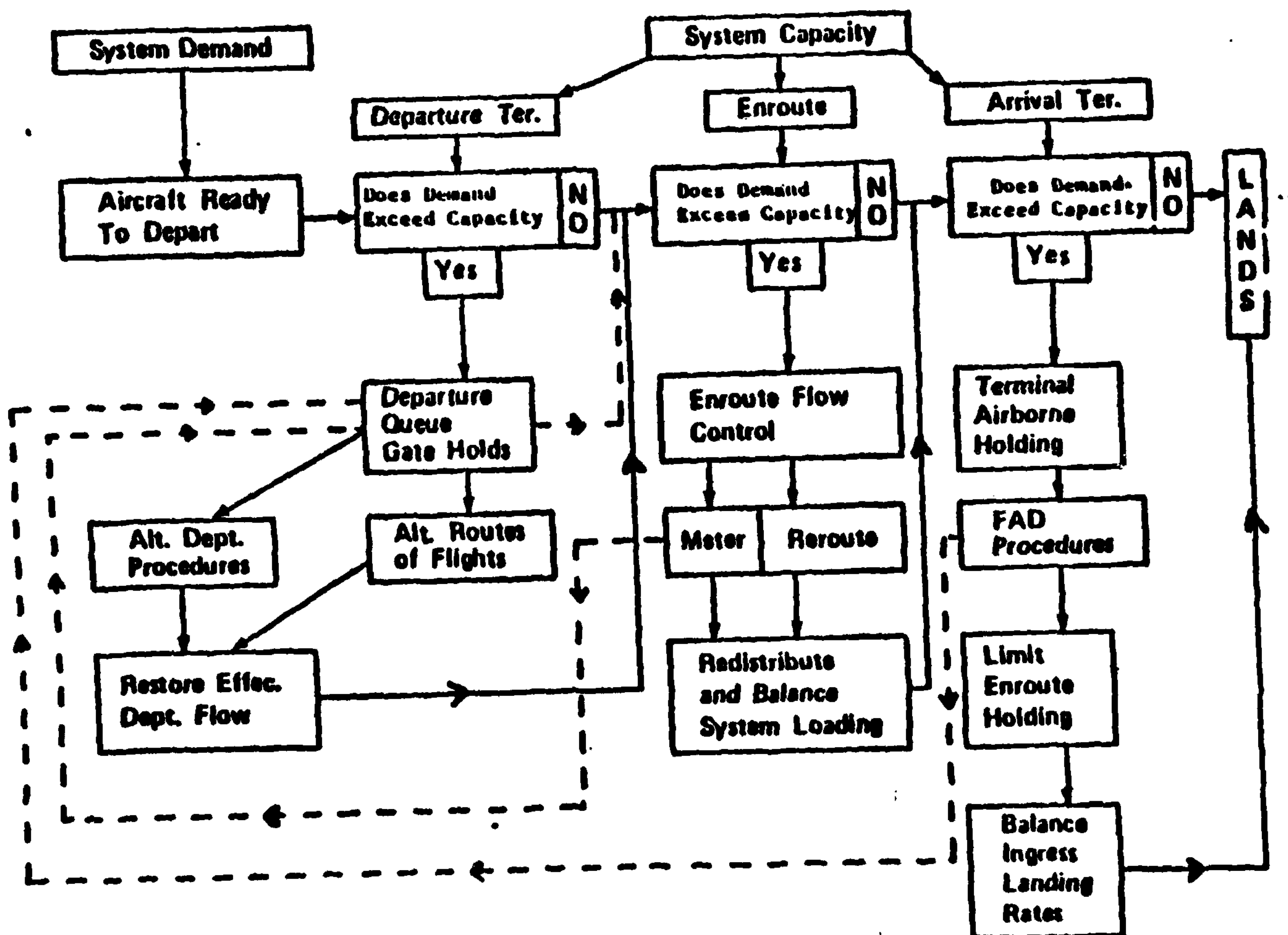
The primary objective of flow control is to keep departing aircraft on the ground when it is expected they will experience delays in either the en route or arriving terminal environment. FAD and QFLOW are discussed below.

FAD

FAD was born out of the need several years ago at Chicago and Denver ARTCC's to limit center operations during periods of reduced acceptance rates at O'Hare and Stapleton terminals. FAD conserves aviation fuel by detaining aircraft on the ground, with the engines turned off, at the departure point until the ATC system can absorb the flight with no more than 30 minutes arrival delay. The procedures are imposed when the delays at O'Hare or Stapleton are expected to exceed one hour for at least three hours.

FIGURE 16

DEMAND/CAPACITY RELATIONSHIP
THE FLOW CONTROL PROCESS



QFLOW

Since FAD became operational, it has been refined so that it can be applied to any terminal in the system. The QFLOW procedures are designed to safely saturate the arrival center and adjacent center airspace to keep a constant demand pressure in the arrival airport. Based on a review of scheduled and other known demand, an estimate is made as to what point in time the arrival center's maximum holding capacity will be reached. Thereafter traffic is subject to the arrival center's approval until the beginning of the following hour, when a quota is implemented by ATCSCC.

The size of the overall hourly quota is based initially on the projected acceptance rate and thereafter on the actual landing and diversion totals. Once a quota has been imposed, departures from the arrival and adjacent center areas to the affected airport will be assigned ground delays if necessary to limit airborne holding to ATC capacity. However, when a forecast of an improved acceptance rate appears reliable in the opinion of the arrival center, flights in excess of the quota will be approved.

Long distance flights which originate beyond adjacent center areas will normally be permitted to proceed to a point just short of the arrival center boundary, where a delay at least equal to the delays (ground/airborne) being encountered by shorter flights will be assigned.

e. Triples, Parallel Runways, and Converging Approaches

There are situations where existing triple parallel, closely spaced parallel, and converging runways cannot be simultaneously used in independent IFR operations. In the case of triple parallel runways, independent IFR operations require provision of a simultaneous procedure for normal missed approaches and protection against blunders. For closely spaced parallel runways, while the runways may have sufficient spacing to allow independent operations, the lack of defined missed approach paths prevents their use in an independent mode. Finally, there are sometimes converging runways which may be used in simultaneous operation in VFR conditions, but cannot be operated under IFR conditions because aircraft may not see each other in the case of simultaneous missed approaches. Many of these situations may allow simultaneous IFR operations if guidance is provided by a microwave landing system (MLS). Table 23 lists the sites where new procedures might be developed in conjunction with use of MLS. Implementation requires installation of MLS at the sites and complementary equipment in aircraft.

3. Nontechnical Actions

In the past, capital investment in facilities and equipment and the introduction of major technological innovations have enabled airports and the FAA to keep pace with the growing demand for air transportation. However, as the costs of expanding existing facilities and constructing

TABLE 23

POTENTIAL APPLICATION OF NEW IFR APPROACHES AT TOP 24 AIRPORTS (Preliminary Evaluation)

Airport	Closely Spaced Parallels	Triple IFR Parallels**	Converging Approaches
ORD		X	X
ATL	X	X*	
LAX	X		
JFK			
SFO	X		
DFW	X	X*	X
DEN	X	X*	X
LGA			
MIA			X
HNL			
BOS	X		X
DCA			
DTW			X*
IAH			X
STL	X		X
PIT	X		
PHL		X	X
LAS	X		X
SEA	X		
EWR	X		X
MSP	X		
CLE	X		
TPA			X
MSY			X

* Separate short runway for GA.

** Could apply elsewhere if technical solutions achieved.

new ones increase, more attention may be devoted to alternate, low investment cost or noncapital-intensive techniques for accommodating increased demand.

These alternatives are generally of three types:

- o Divert traffic from congested airports either by joint agreement of air carriers regarding connecting hubs or through the use of alternative facilities primarily for general aviation (satellite, reliever airports);
- o Impose administrative maximum limits (quotas) on the number and type of operations; and
- o Impose economic rationing (charge variable landing fees, or auction slots).

The last two measures do not physically expand capacity, but they may postpone the need for physical expansion by promoting more intensive and more economically efficient use of existing capacity. The economic methods may also provide financial resources for capital investments to increase capacity. All three methods could be used in combination to form hybrids.

a. <u>Divert Traffic From Congested Hubs</u>

Two approaches may be pursued to offload congested airports— (1) diversion of air carrier traffic or (2) diversion of general aviation traffic. The discussion of airport development options above noted that many of the major congested airports serve as connecting points for domestic and international air carrier traffic. ORD, ATL, DEN, and JFK are prime examples. Less congested airports could serve a part of the connecting air carrier traffic now using congested hubs, thereby relieving congestion and reducing delay. This diversion might be achieved voluntarily through the action of individual airlines. As mentioned in Chapter III, there is evidence of this in the increased traffic at Memphis. Shifts in traffic from Washington National to Dulles International are also being discussed. Active coordination of shifts in connecting traffic may also achieve diversion of air carrier traffic from congested hubs and provide better transportation with less capital expenditure.

Discussions on connecting points could be sponsored by the FAA and attended by representatives of airlines, local airport authorities and the FAA. Perhaps existing airport working groups organized under the Airport Improvement Program (see Section IV.A.4 below) might be adapted for this purpose. Intraindustry planning of connecting traffic modes may require antitrust immunity, but this activity seems exceptionally relevant to the orderly development of a Federal airport and airway system.

Another option for reducing airfield congestion is diversion of general aviation traffic. The satellite airport program (described in Chapter IV.A.1) is aimed at reducing the mix of air carrier and general aviation aircraft in major metropolitan areas by making alternative airports more attractive for general aviation use.

b. <u>Administrative Limits</u>

Flights at an airport may be reduced by imposing a quota on the number of flights scheduled or by banning specific types of operations. Such reductions decrease congestion at the airport. Because the relationship between airport demand and airport delay is nonlinear, a carefully chosen limit on operations at a severely congested airport may drastically reduce delays without a significant reduction in the number of flights. Therefore, quotas and other administrative measures have been (and continue to be) particularly attractive as a means of dealing swiftly and effectively with airside congestion. [1/]

In the long term, however, the impact and benefits of purely administrative measures are less clear because they offer no assurance that economic considerations will play a role in determining who will use a demonstrably (by virtue of its being congested) valuable facility or how this facility will be developed in the future. [2/]

1/ In 1969, the FAA imposed hourly quotas on the scheduling of operations at the three New York City airports, O'Hare International in Chicago, and Washington National. The quotas have been generally credited for ameliorating the traffic congestion situation at these airports. Developments since 1969 have made it possible to eliminate the quotas at Newark Airport. However, the system continues to be in effect at the other four airports.

2/ The purely administrative case is one in which rights for the use of the runways are offered and time slots are allocated either by executive fiat or through negotiations among users. In either situation, it is assumed that no explicit or implicit economic bidding for landing rights and time slots takes place.

Quotas require allocation of operations capacity to individual users. There are a variety of options for making these allocations—first-come-first-served, lotteries, scheduling committees, or the use of some form of priority formula. For the past ten years, scheduling committees have been used to allocate operations at the four United States airports where Federal quotas are presently in force. Although committees have been generally successful, they have encountered increasing difficulties in reaching decisions. Also, scheduling committees have been criticized as being inconsistent with industry competition.

Purely administrative measures, while effective and probably desirable in dealing with short-term congestion problems, tend to be strongly biased toward maintenance of the status quo when used over a protracted period of time. Because economic value is not fully considered in allocating time slots, current users cannot be displaced by others who may derive a higher economic value from the same time slots. Also, the airport cannot obtain through economic mechanisms the information required to determine the need (or lack thereof) for capacity expansion or for an improved (or a reduced) quality of service.

c. <u>Economic Measures</u>

The use of economic incentives rather than administrative controls could alleviate the long-term allocation and development problems if those incentives could be tied to the true costs and benefits of access to the airport. However, this is not a simple task because there are both private and social costs involved.

There are three general forms of economic allocation which might be used to allocate airfield capacity:

- o Peak hour landing fees;
- o Periodic auctions; and
- o Creation of marketable landing rights.

All methods should result in an allocation of airfield capacity to those carriers (and passengers) which place the greatest economic value on the facility. All methods will provide revenues that could be used to improve existing facilities or build new ones (increase supply). The methods themselves, however, do not expand airfield capacity. Expansion of capacity depends on the initiative of Federal and local airport authorities and on physical and social limits to airport development.

There are problems in applying economic measures. For landing fees, the critical problem is determining the equilibrium price. Given that airline schedules change infrequently (three to six months), an iterative process of establishing equilibrium prices could extend over an exceptionally long period of time. The value of use of one airport is a function of access to other airports--air transportation involves a system of facilities. Therefore, ideal airport price structures must be determined for networks of airports, rather than for a single airport in isolation. Also, airports serve several classes of users and there is a problem of determining the marginal costs of service. Pricing based either on marginal cost of service at airports, or willingness to pay, would exclude many current users--particularly general aviation. Users who have relied on traditional, low cost airport access policies have a vested interest in their continuation and will constitute a major impediment to economic measures for allocating scarce airport capacity.

A specific form of auction--one which simultaneously encompasses access to all restricted access facilities and permits recontracting--appears to be the most promising form of economic allocation. It overcomes problems associated with establishing an equilibrium price and can be implemented on a facility network basis.

d. Hybrid Measures

Hybrid measures use a combination of administrative and economic techniques to control demand. For example, the operational surcharge on general aviation movements during peak priods which was imposed by the Port Authority of New York and New Jersey in 1968 coupled with the "quota system" that the FAA imposed in 1969 created such a hybrid environment in the New York area. A similar example is the combination of economic charges imposed by the British Airports Authority and the quotas imposed by the United Kingdom's Civil Aviation Authority at Heathrow Airport.

4. Other Actions

Two other actions which could help alleviate airfield congestion and delay are the use of larger capacity aircraft to reduce the number of operations required to transport passengers and the adoption of organizational devices by the FAA to focus and combine available resources to solve capacity and delay problems at specific sites.

a. Larger Capacity Aircraft

The average seating capacity of aircraft has grown from less than 50 in 1950 to approximately 130 in 1980. In recent years, annual average growth in seats has been about 4.4 seats per year. This increase in average fleet capacity could be maintained by replacement of today's DC-9 and B-727 fleet with new aircraft such as the B-767 as well as adoption of larger derivatives of existing aircraft. Assuming no change in present patterns of service and routes, annual increases of four or five seats per aircraft per year could accommodate 3 or 4 percent annual increases in revenue passenger miles (RPMs) without increases in operations. The FAA projects a 5 percent annual average growth rate for RPMs between 1980 and 1990. Thus, use of larger air carrier aircraft could make a significant contribution to reducing congestion at major terminals.

Because projected air carrier RPMs are growing at a slightly greater rate than seats, and given that air carriers are not the sole users of airports, other actions will probably be required in addition to larger airplanes to prevent future capacity problems.

Increases in competition among airlines and changing route structures can restrain adoption of larger aircraft. Airline deregulation has resulted in increased competition and stimulated changes in route systems.

b. Organizational Devices

Two organizational devices have been adopted by the FAA to focus on specific airport capacity or airport programs. In 1975, the FAA instituted the Airport Improvement Program with the broad objective of reducing delays at the Nation's busiest airports. The program focuses local expertise on the unique problems of each airport in a nationally coordinated effort. Working groups composed of FAA, airport and airline representatives, have been established for ten airports (ORD, DEN, ATL, JFK, LGA, SFO, MIA, LAX, STL, and DFW). The groups determine demand/capacity relationships, identify causes of delay, and recommend and implement improvements. These groups facilitate coordinated actions at individual airports by all impacted parties. Present plans are to expand the number of working groups to include the Nation's 25 busiest airports.

In 1980, the FAA initiated a Metropolitan Area Assessment Program. Under this program, regional offices examine individual primary hub airports, report on the most severe problems, preferred solutions, and the cost and timing of these solutions. This program should provide useful information on the relative severity of capacity problems at different airports and the measures that are being used to resolve them.

In addition to the two organizational devices already adopted by the FAA to focus resources on specific airport capacity/delay problems, other management devices might be appropriate for direct action. A special program office (SPO) or offices could be created to manage specific programs adopted to increase airport capacity and reduce delay. This could be supplemented by incorporation of airport capacity related goals as a part of the job performance standards of appropriate FAA merit pay employees.

B. Airspace Options

Constraints likely to be encountered in providing en route air traffic control at levels projected for 1990 can probably be removed using current technology by providing adequate FAA staff and facilities and by using available unsaturated airspace. Options to provide adequate en route capacity and/or ration scarce capacity may be categorized as air traffic procedures and nontechnical actions. Congestion at the interface between major hub and en route airspace may be a problem without an immediately apparent technical solution.

1. Air Traffic Procedures

Applicable en route aircraft separation standards are 1,000 feet vertical separation below 29,000 feet and 2,000 feet vertical separation above that altitude. A 3 mile horizontal separation is required in a radar environment within 40 miles of the antenna and a 5 mile separation is required if 40 miles or more from the antenna. There must be 5 miles or 2 minutes separation between heavy jets and 10 miles or 4 minutes separation for all aircraft other than a heavy jet following a heavy jet.

Adoption or extension of the following traffic procedures may reduce en route aircraft congestion using current technology:

- o Changes in altitude assignment;
- o Changes in vertical segregation; and
- o Flow control.

Two concepts of en route control involving new technology may provide other alternatives. These are:

- o Pilot based en route control; and
- o Electronic flight rule concept.

As noted in Chapter III.B, substantial growth in low altitude traffic is expected in the future as general aviation and commuter air carrier use of en route control service increase (annual increases of 5.8 and 7.6, respectively). It is likely that certain popular low altitude routes may become congested.

Given the expected evidence of less congested adjacent altitudes, the FAA can alleviate congestion by assigning traffic to the underutilized airspace. Those assignments, however, may differ from the requested altitude and may differ from the optimum cruise altitude of the aircraft. The use of less congested altitudes is dependent on adequate FAA facilities and staff to accommodate the increased traffic.

Although air carrier use of en route traffic service will not constitute the largest increase in demand over the next decade, there will be some growth (1.7 percent per year) which may create or exacerbate existing congestion. Air carrier aircraft are the predominant users of high altitudes. Vertical separation above 29,000 feet is presently set at 2,000 feet. Thus, one option for reducing air congestion which may develop on high altitude routes is to reduce the vertical separation requirement, possibly to 1,000 feet (the requirement at lower altitudes). The FAA has begun research into reducing vertical separation above 29,000 feet throughout the ATC system. The research program will cost $6 million and take five years.

System flow control and its variations have already been described in connection with airfield options (Section IV.A.2 above). Flow control can be used to mitigate the impact of en route delays by detaining aircraft on the ground or reducing en route airspeeds.

The electronic flight rules (EFR) concept is an attempt to provide a flight environment that would permit VFR operations in IFR weather. Electronic devices would provide the pilot with the same information provided by the eyes in VFR weather. EFR would allow suitably equipped aircraft to use today's VFR operating procedures in certain airspace under IFR conditions, avoiding the constraints of an IFR flight plan and an ATC clearance. The control system would automatically provide control instructions when necessary, but would otherwise permit the aircraft to proceed undisturbed.

The FAA would benefit from EFR through reduced costs of labor, facilities, and equipment. Users would be freed from the costs and constraints of the present ATC system when operating under EFR. Also, under an advanced EFR technology, pilot-based ATC would be possible. Operators who chose to properly equip and to assume greater ATC responsibilities would use EFR-provided information to protect themselves from other aircraft.

EFR is presently in the conceptual stage, and basic system design questions are unanswered. For example, would such a system be ground based or aircraft based? Moreover, the equipment required by EFR is not well-defined. For example, would DABS be required? Answers to such questions are so remote that implementation of EFR is impossible before the 1990's. Nevertheless, EFR is a potentially useful future system.

2. Nontechnical Options

The largest growth in use of IFR en route service is expected to involve general aviation and commuter carriers at low altitudes.

If congestion develops, available capacity could be rationed out using a combination of quotas, administrative procedures, and/or economic measures similar to those described under airfield options (Chapter IV.A. above). Previous discussion on application of these options to terminal capacity is, therefore, relevant to en route capacity.

Given that much of the potential increase in congestion may be associated with two classes of users, the use of direct charges for en route service seems particularly relevant. Direct charges will simultaneously provide financial resources for system expansion when such expansion is considered desirable by users, and it will allow users to express an evaluation of the value of service by their willingness to pay for service provided.

As with airfield access, en route service fee differentials could be established for both time of day and en route sectors transited. If necessary for air transportation system planning purposes, en route air carrier operations could be allocated via a simultaneous auction process similar to that being evaluated for allocation of runway capacity.

C. Summary

Table 24 lists technical and procedural changes which might increase airfield capacity or reduce (mitigate) aircraft delay. With the exception of wake vortex alleviation/detection, dual glideslopes, reduced runway occupancy time, and traffic sequencing, all appear relatively

TABLE 24

CHARACTERISTICS OF OPTIONS TO INCREASE AIRFIELD CAPACITY/REDUCE DELAY

	Physical/ Technical Possibility	Type of Impact	Cost		Operator Acceptance	Community Acceptance
			FAA	User		
Short Runways	Moderate to High	Increase Capacity	$10 Million each	Unknown	High	Moderate
Satellites/Relievers (Divert GA Traffic)	High	Increase Capacity	$93 Million	Low	AC - High GA - Moderate	Moderate
Reduce Runway Occupancy Time	Low	Increase Capacity	Unknown	Unknown	Low	Moderate
Wake Vortex Alleviation and Detection	Low	Increase Capacity	Unknown	Unknown	Moderate	Moderate
Dual Glide Slopes	Low	Increase Capacity	Low	Moderate	Low	Low
Traffic Segregation	Moderate	Increase Capacity	Low	Low	Moderate	Moderate
Traffic Sequencing	Low to Moderate	Increase Capacity	Unknown	Low	Low to Moderate	Moderate
Parallel/Converging Approaches	Moderate	Increase Capacity	Low to Moderate	Moderate	Moderate	Moderate
Flow Control	Moderate	Mitigate Delay	Low	Low	Moderate	Moderate
Divert AC Traffic - Agreements	Moderate	Reduce Delay	None	Unknown	Low to Moderate	Moderate

feasible from a physical or technical perspective. Options associated with airport development or traffic procedures (except flow control) generally increase capacity. The nontechnical options (with the exception of using satellite airports to divert general aviation traffic) either reduce delay or delay cost. Several characteristics of options, especially operator acceptance and community acceptance, are based on the experience and judgment of FAA analysts.

The expansion or creation of airports may be the most costly option, but it may be the only option capable of increasing capacity in some instances. This option would also have a high user cost assuming development costs were recovered from users. Nontechnical options (possibly excepting the diversion of general aviation traffic through satellite airports) are relatively inexpensive, but will probably result in substantial user cost. Airport development and air traffic actions to increase capacity are likely to be more acceptable to aircraft operators than nontechnical actions.

Table 25 indicates the likely applicability of airfield options to specific sites. At airports with a relatively high proportion of general aviation traffic, probably the most relevant strategies are those that seek to either accommodate these general aviation aircraft or divert them to alternate sites. These options are short runway development and satellite and reliever airports. Actions to provide overall increases in runway capacity such as traffic sequencing, greater simultaneous use of

TABLE 25

POTENTIAL AIRFIELD APPLICABILITY OF OPTIONS TO INCREASE CAPACITY/REDUCE DELAY

	High GA							Alternate Airports				Extra Capacity							
	OAK	IAH	SNA	LAS	MEM	PHX	SAN	SFO	DFW	ORD	DCA	ATL	BOS	DEN	LAX	PHL	STL	LGA	JFK
Short Runways									1/	1/		X		X		X	X		X
Satellites/Relievers (Divert GA Traffic)	X	X	X	X	X	X	X	1/	1/	1/	1/	X	X	X	X	X	X	X	X
Reduce Runway Occupancy Time	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Wake Vortex Alleviation and Detection	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Traffic Sequencing	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
Parallel/Converging Approaches		X		X	X	X		X		X		X	X	X	X	X	X		
Flow Control									X	X		X	X	X					
Divert AC Traffic – Agreements								X	X	X	X	X	X	X	X	X	X	X	X

1/ Physically possible but not considered a good alternative.

parallel runways (including triples) and converging approaches, as well as wake vortex alleviation/detection or dual glideslopes, if technically possible, are relevant for all congested airfields.

There are four airports where reasonably close alternate major airports offer potential congestion relief—SFO, DFW, ORD, and DCA. For these airports, the most relevant options are those that would encourage some shift of air carrier traffic to the alternate sites. Another option relevant to SFO, DFW, ORD, and DCA is diversion of air carrier traffic through negotiated agreements.

For the remaining airports, the only real options are to increase physical capacity for air carriers and/or divert or prohibit additional air carrier traffic. While general aviation uses these airports, it is only a small fraction of total operations (see Table 14). For these sites, the 1990 ratio of non-GA operations to PANCAP is expected to generally exceed 1.25. If physical expansion is possible, either at or in the vicinity of ATL, STL, or DEN, it should be encouraged. In addition, perhaps some international traffic at JFK could be shifted out of the region. Agreements to divert future air carrier traffic appear relevant for this last group of airfields.

Table 26 lists technical and procedural changes which might alleviate future en route congestion. All actions, except the nontechnical ones, increase capacity. Only the two options involving new en route control concepts are of uncertain technical status. The degree of operator acceptance is based on the experience and judgment of FAA analysts.

TABLE 26

CHARACTERISTICS OF OPTIONS TO INCREASE AIRSPACE CAPACITY/REDUCE DELAY

	Physycal/ Technical Possibility	Type of Impact	Cost		Operator Acceptance
			FAA	User	
Alternate Altitude Assignment	Moderate to High	Increase Capacity	Low 1/	Low to Moderate	Moderate
1,000 Foot Vertical Separation Above 29,000 Feet	Moderate	Increase Capacity	Low 1/	Low	High
En Route Flow Control	Moderate	Mitigate Impact of Delay	Low to Moderate	Low	Moderate
Pilot Based Control	Unknown	Increase Capacity	Low?	Low to Moderate	Moderate to High
Electronic Flight Rule Concept	Unknown	Increase Capacity	Low?	Low to Moderate	Moderate to High

1/ Must consider additional cost of increased scale of en route facilities and equipment.

V. CONCLUSIONS

This analysis is concerned with the availability of airfield and airspace capacity to meet present and future aircraft demand. The measurement of capacity and demand for any particular airfield or segment of airspace requires a detailed analysis beyond the scope of this present effort but, drawing upon the available data and using past analyses, several conclusions have been reached which may broaden public awareness and aid government and industry planning.

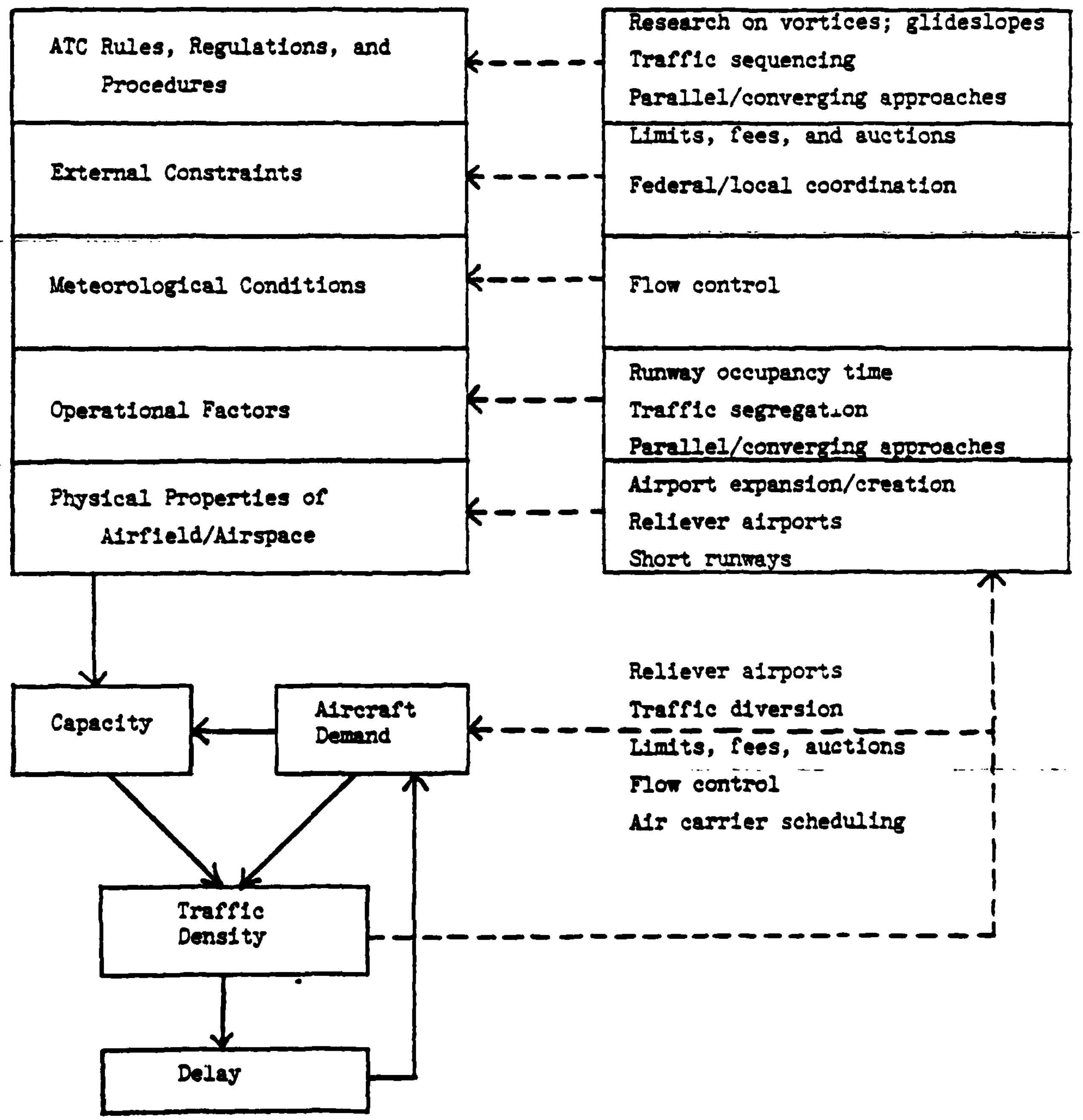
Air carrier delays have averaged in the range of four to six minutes per operation in recent years. This range appears to be tolerable to both air carriers and passengers. Nearly all of this delay occurs at airfields; there is general agreement that en route delay is insignificant. Those delays which appear excessive are either caused by severe weather or are limited to a few major airports with high capacity utilization. The cost to air carriers of delays over which some control may be exerted, essentially those delays related to capacity utilization, may be about $0.9 billion. The total cost of delay may be about $1.4 billion.

Over the next ten years, there is not expected to be any significant en route congestion problem, although some centers using 9020-A computers may have to offload some present computer functions or impose aircraft delays to prevent congestion. There may be a significant airfield capacity problem, however, if present forecasts for aviation growth are accurate. The total cost of delay may grow to about $2.7 billion by 1991, about $1.7 billion of which may be subject to some control. As many as nineteen airports could face delays which might be considered intolerable if no action were taken. Much of the anticipated growth is in general aviation, and seven of those nineteen airports could alleviate their capacity shortfall by diverting some general aviation traffic or redistributing traffic into off peak hours. Another four airports may find sufficient relief from diversion of air carrier traffic to other nearby airports. There remain, however, eight airports where diversion of general aviation traffic will not provide adequate congestion relief and alternate facilities for air carrier traffic are not readily identifiable at this time. While new air traffic procedures involving the simultaneous use of parallel and converging runways and/or traffic segregation may provide some capacity increase, congestion will remain a problem. Many of these eight airports serve as key connecting points in the national air transportation system or links to the international air transportation system. To restrain delay at these sites, nontechnical actions such as quotas and user charges may be required, and capacity should be increased if possible through the construction of more runways, either on the existing or alternative sites.

Some portion of delay is attributable to airline scheduling practices and could be alleviated immediately by changes in those practices. The existence and tolerability of these delays casts doubt on the ability of the FAA to significantly reduce delay through the measures open to it. Other portions of delay are the result of ATC rules, weather, aircraft performance characteristics, and other factors which may be researched individually. Significant benefits from such research cannot be expected to be realized in the near future. Figure 17 summarizes the options available to increase capacity or reduce delay.

FIGURE 17

SUMMARY OF CAPACITY/DELAY OPTIONS



APPENDIX A

AIRPORTS INCLUDED IN SDRS

Airport Identifier	Airport
ATL	Atlanta International
BOS	Boston Logan
BWI	Baltimore-Washington International
CHS	Charleston AFB Municipal
CLE	Cleveland Hopkins International
CVG	Cincinnati Greater International
DCA	Washington National
DEN	Denver Stapleton International
DFW	Dallas - Ft. Worth Regional
DTW	Detroit Metropolitan Wayne County
EWR	Newark
HNL	Honolulu
IAD	Dulles International
IAH	Houston Intercontinental
IND	Indianapolis International
JAX	Jacksonville International
JFK	John F. Kennedy International
LAX	Los Angeles International
LGA	LaGuardia
MEM	Memphis International
MIA	Miami International
MSP	Minneapolis - St. Paul International
MSY	New Orleans Moisant
ORD	Chicago O'Hare International
PHL	Philadelphia International
PHX	Phoenix Sky Harbor International
PIT	Pittsburgh Greater International
RDU	Raleigh - Durham
SEA	Seattle - Tacoma International
SFO	San Francisco
STL	St. Louis International
TPA	Tampa International

APPENDIX B

ANALYSIS OF SCHEDULED OPERATIONS AT ATLANTA (ATL)

FRIDAY, AUGUST 4, 1978

The percentage of arrivals out of total operations on this day is 50.1 percent. The percentage of arrivals out of total operations for each hour between 0900 and 0100 follows:

Hour	Percentage Arrivals	Total Operations
0900	69.7%	99
1000	20.2	94
1100	68.8	77
1200	30.9	81
1300	58.6	58
1400	42.4	85
1500	66.2	74
1600	46.7	92
1700	60.0	105
1800	24.1	87
1900	89.2	83
2000	10.6	85
2100	87.5	48
2200	17.4	46
2300	94.5	73
0000	5.9	51

If the hours are paired off sequentially (0900-1000, 1100-1200, etc.), they form eight pairs, each of which exhibits an hour of above-average arrivals followed by an hour of below-average arrivals. The mean difference between the paired percentages is 49.5 percent. Conventional statistical tests for runs conclude that the sequential percentages of arrivals are not randomly distributed.

APPENDIX C

SDRS DELAYS
(Annual Average, Minutes per Operation)

Airport	1976	1977	1978	1979	1980
ATL	8.85	10.61	10.11	10.81	9.46
BOS	6.60	7.49	6.98	7.90	7.15
BWI	4.28	3.89	4.15	4.61	4.21
CHS	3.75	3.89	3.79	3.58	3.29
CLE	4.48	4.89	4.74	4.82	4.22
CVG	3.01	5.63	3.67	3.37	2.88
DCA	6.22	6.82	6.67	6.74	6.41
DEN	6.42	7.01	9.52	8.78	8.09
DFW	5.16	4.46	4.88	5.67	5.23
DTW	4.13	4.67	4.91	4.74	3.99
EWR	7.60	7.36	7.93	8.12	7.79
HNL	4.58	5.47	5.57	5.80	5.45
IAD	5.25	4.92	4.88	5.41	4.33
IAH	4.19	4.13	4.93	5.42	5.17
IND	3.63	3.99	4.03	4.04	3.41
JAX	3.79	3.74	3.75	3.73	3.63
JFK	10.75	9.99	11.14	9.76	9.25
LAX	4.76	5.07	6.42	6.32	7.09
LGA	9.35	8.20	9.34	9.76	9.31
MEM	3.37	3.27	3.49	3.77	3.59
MIA	5.27	5.00	5.53	5.44	6.01
MSP	2.80	3.27	3.26	3.68	3.31
MSY	3.04	3.93	4.52	5.03	4.41
ORD	9.09	9.30	9.67	10.17	8.89
PHL	6.99	6.59	8.51	6.94	5.86
PHX	3.43	3.45	4.05	4.14	4.80
PIT	5.48	5.77	5.87	5.97	5.89
RDU	3.60	3.58	4.00	4.17	3.92
SEA	4.08	3.63	3.59	4.44	4.66
SFO	5.42	4.95	4.62	5.22	5.89
STL	4.75	6.07	6.31	7.63	7.15
TPA	3.79	3.66	4.27	4.47	4.18

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